ACTA PATHOLOGICA ET MICROBIOLOGICA SCANDINAVICA
SUPPLEMENTUM XLVIII

HJALMAR SJÖVALL

THE GENESIS OF SKULL AND BRAIN INJURIES

AN ANATOMICAL AND PHYSICAL STUDY

1943

EJNAR MUNKSGAARD - COPENHAGEN

THE GENESIS OF SKULL AND BRAIN INJURIES

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AKADEMISK AVHANDLING, SOM MED TILLSTÅND AV MEDICINSKA FAKULTETEN I UPPSALA FÖR ERNÅENDE AV MEDICINE DOKTORSGRAD OFFENTLIGEN FÖRSVARAS Å PATOLOGISKA INSTITUTIONENS FÖRELÄSNINGSSAL DEN 27 MAJ 1943 KL 10 F. M.

AV

HJALMAR SJÖVALL
MED. LIC., NORRL.

LUND
HÅKAN OHLSSONS BOKTRYCKERI
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ACTA PATHOLOGICA ET MICROBIOLOGICA SCANDINAVICA
SUPPLEMENTUM XLVIII

FROM THE PATHOLOGICAL AND MEDICO-LEGAL INSTITUTION AT THE
UNIVERSITY OF LUND. CHIEF: PROFESSOR E. SJÖVALL

THE GENESIS OF SKULL AND BRAIN INJURIES

AN ANATOMICAL AND PHYSICAL STUDY

BY

HJALMAR SJÖVALL

WITH A SUPPLEMENT:

THE EFFECT OF AN IMPACT ON A SPHERICAL LIQUID MASS

BY

ADOLF ANZELIUS

LUND
HÅKAN OHLSSONS BOKTRYCKERI
1 9 4 3

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ACKNOWLEDGEMENTS.

The idea first prompting the present work, i. e. that contre-coup injuries in some way result from pressure below atmospheric, was given to me by the study of Docent Ernst Bárány's thesis (A Contribution to the Physiology of Bone Conduction, Uppsala 1938). His results (Chap. IX) agree with the assumption that, in bone conduction, the inertia of the brain causes it to remain still inside the oscillating skull.

As soon as I had decided to elaborate this idea, I realized the necessity and value of a patho-anatomical exposition of this type of injury. I accordingly applied to my father, Professor Einar Sjövall, for access to the wealth of material, collected under his direction and mainly by him in person, in the archives of the Medico-legal Institution in Lund. The investigation has subsequently been extended to include the skull and brain injuries in general, and an anatomical material has been collected and treated by me at the Pathological Institution in Lund (Chief: Professor E. Sjövall).

I have been assisted in the photographic registration of this anatomical material by Mr. O. Mattsson at the Anatomical Institution in Lund (Chief: Professor G. Backman).

The statistical calculations have been checked at the Swedish State Institute for Human Genetics and Race Biology, Uppsala (Chief: Professor G. Dahlberg).

The experimental physics examinations have been made at the Neuro-physiological Laboratory of the Royal Caroline Institute, Stockholm (Chief: Professor R. Granit). I am also indepted to the physicist of that laboratory Mr K. T. Helme for helpful discussions. Instruments for these experiments have been produced at the factories of Jährn's Electrical Company, Stockholm, under the direction of *med. lic.* R. Elmqvist and *med. lic.* P. Petersen.

Financial support for these investigations has been granted from the foundation *Therese och Johan Anderssons minne*, Stockholm.

The translation into English has been made by Carolyn Hannay-King, M. A., Lund.

To all those who have thus in different ways furthered and made easier my work, I beg to tender my cordial thanks.

To Docent Adolf Anzelius, Royal Technical College, Stockholm, I offer special thanks for his great interest in my work. He has most kindly agreed to work out, from a theoretico-physical viewpoint, the course of impact in an enclosed liquid mass — a hitherto unsolved problem, which I am incompetent to deal with. Docent Anzelius's calculations will be found as a supplement to this book.

Lund, April 1943.

H. S.

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Chapter I.

The problem.

Severe violence to the head assumes a position of its own among different types of injuries, partly because of its clinical picture with unconsciousness as the dominating symptom, partly because of its great danger to life. Interest in this is found in medical literature in the most divergent special branches. Thus we find skull fractures described even in the anatomical textbooks, and unconsciousness discussed in physiology and internal medicine. By virtue of its nature of accident, such violence comes primarily within the sphere of the surgeon, however, and calls for his help in its immediate treatment. It is often connected with direct injuries to the organs of sight and hearing, or displays symptoms from these organs via injuries to brain and nerves. The later consequences of such violence (in the survivors) usually fall within the sphere of internal medicine or psychiatry, as well as of insurance medicine.

Seriously threatening life as they do, these injuries come to a large extent within the experience of the pathologist, and the general nature of injuries to brain and skull has long been known and described. Analyses acquire a special value in those cases where the autopsy is for legal purposes, and latterly there has been an increasing attempt to draw conclusions as to the way in which an injury was inflicted from its anatomical picture, above all in the increasingly common highway accidents. Needless to say, such an analysis demands a clear idea of the physical aspect at the time of the injury.

The present author limits the very extensive problem by only including the patho-anatomical and physical viewpoints, complemented by some medico-legal details of interest. Thus, not only

the questions of therapy and prognosis are passed over, but also such viewpoints as to the genesis of the injury that might be got from a clinical examination of injured persons. Nor will the author go into the discussion of the onset and underlying factors of unconsciousness.

Instead, this work will elucidate the problem of the genesis of injuries to the skull and brain visible to the naked eye. Two materials are used to this end: 1) a series of medico-legal autopsies, which are statistically treated, and 2) about fifty specimens of injured human brains which have been examined macroscopico-anatomically, and some microscopically also. Finally, a uniform physical theory for all injuries to skull and brain is presented, based on a thorough survey and discussion of earlier works, and on the author's own results.

Chapter II.

Review of the literature.

Knowledge of injuries to the skull and brain can be traced back as far as Hippocrates, and the old literature contains various contributions to this question. Nevertheless, the anatomical observations were few and hardly systematic, and the attempts at explanation were stamped by the general medicinal notions of the time. The more modern discussion can be said to have begun when L'Academie Royal de Chirurgie in Paris offered a prize for a theory of injuries to the head 'par contre-coup' with an account of the practical consequences which could be drawn from it. The secretary of the Academy, Louis, collected (1766) the anatomical and surgical facts of the time as a foundation for the work. It appears that at that time contre-coup injuries implied all injuries to skull, cerebral membranes and brain, which were not immediately due to the object causing the injury, including, of course, the known cerebral injuries on the opposite side. Under such circumstances, the theories, too, must of course be sweeping. The prize-winning works of Saucerotte, Grima, Sabouraut, and Chopart were published by the Academy in the year 1778. The theory that came to be accepted was Saucerotte's: namely, that vibrations proceeded from the point of impact into the bones of the skull, which vibrations reassembled at the opposite pole, thereby acquiring at this spot fresh force to fracture the skull and injure the brain. The other authors have the more modern view that the skull is deformed in its entirety, and Chopart gave a description anticipating the theory of elastic impact.

In complete agreement with Saucerotte, Petit (1774) initiated the view that the clinical picture (concussion) in injuries to the skull, with unconsciousness as outstanding symptom, is due to the

wave motions in the skull proceeding to the brain, whose functions they lower or inhibit 'immédiatement'.

As it has progressed, the discussion has gradually been enriched with ever more facts (clinical and anatomical observations and experiments) and very varying theories based upon them. The discussion falls roughly into four independent lines: 1) Fractures of the skull from blunt violence. 2) Injuries to the brain from blunt violence. 3) The concussion problem from a physical viewpoint. 4) Gunshot injuries.

1. Skull fractures from blunt violence.

Aran (1844) carried out numerous experiments on cadavera to produce basis fractures, and considered himself able to lay down as a general rule that these fractures start from the site of impact or its immediate vicinity, and then radiate down to the base of the skull, where there is least resistance. Although a number of his cases (both clinical and experimental) proved exceptions, he nevertheless established the rule that a fissure of this sort takes the shortest path down to the base. Aran questioned the theory of vibrations: »The skull is far too irregular for mathematical calculations», and fractures by contre-coup are questioned generally (as also by many previous authors). Probably we have here misinterpretations of cases with two external impacts.

During the following decades two new viewpoints came to the fore: the anatomical structure of the skull, and its elasticity and strength as an entirety. Trélat (1855; quoted according to Félizet and Doepfner) maintained that the skull had six buttresses, which in his opinion led the fractures down to one of the fossae, where they were in addition very apt to run into the foramina of the base. Félizet (1873) studied a large number of skull fractures, and classified them as follows:

1) Fractures à grand fracas, the large comminuted fracture systems, for which he denies any possibility of systematical treatment.

2) Fractures communes a) l'enfoncement circonscrit de la voûte
b) les fissures limitées ou irradiées.

He considered Aran's rules to hold for the last-mentioned, and found the fissures to run on the whole between the buttresses and, practically speaking, in such a manner as always to avoid what he called 'centre de résistence', namely the front part of the foramen occipitale magnum and the pars basilaris. Though vouchsafing no physical explanations, he showed by experiment the deformation (flattening) of the skull round the point of impact in plane violence, a deformation that appeared on the surface both of the skull and of the brain.

Experiments touching the elasticity of the skull were made by von Bruns (1854), Hermann (1881), and above all Messerer (1880 and 1884). They showed that the skull as a whole is deformed by compression between two planes. A shortening in the direction of the pressure is compensated by an expansion of the equator. Sufficiently hard pressure causes fractures, which run as meridians from pressure pole to pressure pole and which are similar in appearance to the basis fractures that occur. It was clear to these authors that it was the site of impact alone that determined the general course of the fracture, independent of possible irregularities in the structure of the skull.

A number of statisticians of the time (Hewett, 1858, and Schwartz, 1872) seem also to have argued for this view and against Félizet's buttresses. The introduction of physics banished the mystery round basis fractures and only two forms remained in Hewett's statistics as independent fractures, i. e. fractures in the orbital roof and breaking of the dorsum sellae turcicae.

von Wahl (1882) gave an account of the physical theory and divided skull fractures into bending fractures ('Biegungsbrüche'), which run circularly round the site of impact, and breaking fractures ('Berstungsbrüche') running in the direction of the meridian outwards from this point. The two types can be combined, and all direct skull fractures are included in this system. In his later work Messerer (1884, quoted according to Greiffenhager) also made experiments with blows on the heads of cadavera, and produced different forms of fracture according to the form of the striking surface (wide and plane, and limited and rounded, respectively). von Wahl (1888) discovered that, in different fracture systems, either the bending fractures, or the breaking fractures might predominate, and this could (with reference to Messerer)

be explained by saying that either 'mehr die Druckkomponente (breaking fracture) oder die Stosskomponente (bending fracture) zur Geltung kommt'.

It is worth mentioning that already in 1869, Forgues, in a work not considered in the literature, described meridional fissures under the title 'fracture par éclatement', and explained them in the same way as Messerer and von Wahl. As regards different types of fracture arising from different forms of violence, Aran observed already in 1844 that a 'marteau à autopsie' only gave 'fractures par enfoncement, très circonscrites', whereas 'des marteaux lourds et volumineux, connus sous le nom de masse de fer' must be used for 'fractures irradiées'. In his experiments, Perrin (1878, quoted according to Dulles) got indirect fractures (meridional fissures) from free falls, but direct fractures (limited) from blows on the head — not, however, from blows on the occiput and the sinciput, which also gave indirect fractures. The observation was confirmed by Walton (1904). Butler (1923) differentiated between two types of situations involving violence: 1) The object inflicting injury is moving, but the head is still, e. g. a falling tile. 2) The head is moving, e. g. a fall to the ground. He observed that contre-coup injuries were sustained only in the latter case. (The observation is correct, but the explanation unsatisfactory. From the point of view of physics, it makes no difference which of the colliding objects is moving in relation to the earth).[1]

In the discussion that followed, the physical explanations thus given were generally accepted, and augmented in different details. Dulles (1886) appended a number of corollaries to Messerer's measurements, which made it possible to forecast the probable course of the meridional fissures caused by violence to different parts of the skull. Several authors have been at variance concerning one detail, namely, at which point of the meridian the fissure starts (Treub, 1884; Greder, 1885; Dulles, 1886; Greiffenhagen, 1887; von Knorre, 1890). Von Knorre's formula, where he differentiates between meridional fissures arising from unilateral and bilateral force respectively, may well be collective. The latter begin at the equator and run out towards both poles of pressure, the former begin at the point of impact and run for a longer or shorter distance from it.

[1] Sentences within brackets = The author's remarks.

Another physical factor in the explanation of the more extended skull fractures was first pointed out by Evler (1891); this was the effect of the rapid increase of pressure on the practically fluid content of the skull, when the site of impact (or of the pressure poles) bulges inwards towards the cranial cavity. The 'hydrostatic' pressure thus produced has an explosive action on the skull, as in gunshot injuries (see below). Tilmann (1902) and Thoma (1909) share this view.

Thoma (1909) gave a careful analysis of the deformation of the skull by pressure which conforms with the theory of elasticity. Here for the first time, we may say, the physical theory as to skull fractures has been completely and clearly presented. If the skull is thought of as a hollow sphere, bilateral pressure will distort it into an ellipsoid, and the material will hereby be exposed to two different kinds of strain, which Thoma calls 'Biegung' (alteration of the curvature: an elongation of the radius at the points of pressure, a shortening of the meridional and an elongation of the equatorial radius at the equator) and 'Dehnung' (an extension of the material in the direction of the parallels and its compression in the direction of the meridians). These different strains combine to form tensile and compressive stress, whose principal planes of stress coincide with the meridians and parallels of the hollow sphere. Earlier investigators have found the breaking-point of the bone substance under tension to be 10.8 kg/mm^2, and under pressure to be 14.7 kg/mm^2. Fractures therefore take place either in the meridians or the parallels, and begin in those parts of the bone where the tensile stresses exceed the breaking-point, irrespective of whether this occurs in the outer or inner surface of the hollow sphere. Increased pressure inside a hollow sphere provides stresses which are the same in all directions and which cannot, therefore, influence the direction of the fissures, though they can increase the length of one already there. Thoma maintained, however, that it is possible for the contents of the skull to escape from pressure into the different foramina of the skull. (He did not analyse what happens when the skull is struck.) The skull, however, is *not* a sphere, but an elongated, irregular ellipsoid, and Thoma pointed out that compression along a long axis must make it more spherical, and consequently entail an increase of volume, whereas compression along a short axis

entails a volume decrease. On these considerations, Thoma classified the skull fractures thus:

1) Local fractures, immediately due to the object inflicting them.
2) Deformation fractures, resulting from the mechanism described above.
3) Explosion fractures, resulting from projectiles with sufficiently great kinetic energy (see below).

Braquehaye (1895) and the same author together with Chipault (1895) illustrated the deformation of the skull from blows by inserting an air-drum fitted with a registering Marey capsule in a trephination; this was done both on living dogs and on cadavera. The experiments on animals showed that there was an initial pressure above atmospheric in the contents of the skull at the point of violence, and initial pressure below atmospheric at the diametrically opposite side (the opposite pole). When registering capsules were placed at both poles, Braquehaye was able to show that the negative deflection at the opposite pole began 0.0019 seconds later than the positive one at the point of violence. This confirmed Félizet's finding of a 'cone de dépression' and Duret's statement (1878) that a 'cone de soulèvement' ('cette donnée mécanique', p. 29) was set up at the opposite pole. The experiments on cadavera were made by inflicting blows at different points of the free skull, while the capsule was placed at one fixed spot (the occiput, the temple, or the forehead). Blows closest to the capsule (about as far away as to the nearest adjacent buttress) gave an initial pressure above atmospheric, and beyond that an initial pressure below atmospheric. Instead of the two cones, Chipault and Braquehaye therefore speak of a 'zone de dépression' round the point of violence, and a 'zone de soulèvement' (= the rest of the skull).

The physical theory thus constructed also explains the two types of isolated basis fracture observed but left unexplained by Prescott Hewett (1858), namely, fractures of the orbital roof and of the dorsum sellae. The deformation of the skull also sets up stresses in the tentorium cerebelli, which pull the dorsum sellae backwards and fracture it. Ipsen (1898) collected 23 cases of fracture of the orbital roof from the literature, and added two of his own. He remarked that one sometimes observes dislocation of

the bone fragments down towards the orbit, and a study of his material shows these cases to be gunshot injuries. In one of his own cases with blunt violence on the occiput, the fragments are, on the other hand, dislocated inwards in the direction of the cranial cavity. Tilmann (1902) confirmed these findings and found them explained in gunshot injuries by the pressure above atmospheric set up in the contents of the skull, in blunt violence on the occiput by the pressure below atmospheric which he ascribes to the inertia of the contents. (He did not mention the discoveries made earlier by Chipault and Braquehaye, which confirm this).

Schroen (1902) made an attempt to construct a physics of impact. He began with an analysis of a row of molecules, deduced how this row must be compressed during the impact, and determined the force of expansion resulting from this. He then applied these results without further calculation to discs and solid spheres, and also to the skull. (These extremely simplified deductions do not help very much in understanding the injuries to brain and skull. They enabled Schroen to explain obviously erroneous observations such as the diminution of the brain after blows, 'Stückbrüche' round the opposite pole, and so on).

Ipsen (1910) maintained that the tendency of the meridional fissures to make their way down to the base of the skull is due not so much to what earlier authors assumed to be a lesser resistance in the latter, but to the fact that it represents a plane segment surface in an otherwise evenly curved hollow sphere, and is therefore subject to greater stresses. Homogeneous models, too, break in a plane-off surface element of this kind.

Duret (1910) and his pupil Poulain (1912) lauched a new anatomical theory of fractures, based on the assumption that the skull rests on *one* firm column (the vertebral column) with a capital (the neck joint), whence six buttresses (the six described by Trélat and Félizet) bear up the simple vault. In their opinion the long fracture fissures result from a shearing of two arbitrary halves of the vault between the point of impact on the one hand, and the vertebral column on the other. (This view can be proved erroneous, for one reason because the fractures proceed from the actual site of impact — this also applies in plane violence — and not beside it, and also because the fractures often run obliquely through the capital or far out to the sides, transversing the

buttresses. In his great work (1919—22), Duret nevertheless adhered to this view).

The rôle of the vertebral column as contributory factor in the fracture mechanism is, on the other hand, clarified in the long discussion on ring fractures. This discussion has been completely and fully reviewed by Le Count and Hockzema (1934). It may be that in any one case limited, ring-shaped fractures round the neck joint may result from the body's inertia during violence to the sinciput, and possibly also from the inertia of the head when the buttocks or feet are struck. According to the above-mentioned authors' extensive material (1278 cases), however, ring fractures result more frequently from the junction of two or more meridional fissures at the opposite pole of the skull, or from the uniting of such fissures by a cross break near the cervical joint.

During the last decades only a few works have dealt with the mechanism of fractures to the skull. Vance (1927) published material from 512 autopsies, which does not, however, have any very great theoretical interest. Noteworthy, however, are the observations of depression fractures in the roof of the skull, caused by objects with limited area of impact coming into contact with the skull, usually blows with murderous weapons. The bone is 'broken and depressed in a limited, sharply defined area of the vault'. Such instruments with limited area of impact also cause other forms of fracture, however, but then it is often a case of 'large instruments' and 'violent blows'. Schwarzacher (1937) stated that, for fracture of the skull, an energy of 2 kgm per cm^2 of area of impact is required, and that 5—10 kgm/cm^2 cause extended damage. If the mass of the object inflicting the injuries and the size of the area of impact are known, it is possible to calculate the requisite velocity of collision for a given injury. It is mentioned by way of example that an axe can cause fracture of the skull, but not a clenched fist. Using a technical term, 'Kleben des Schlages', Schwarzacher implied it was possible that the duration of the blow had a great deal to do with the breaking of bones. Panning (1940) collected clinical and experimental material concerning skull fractures in infants. He showed that these fractures also radiate from the point of impact, but that they follow, if possible, the direction of the bone rays, and that, on account of the soft, broad sutures, the fractures in adjacent bones are

often displaced parallel to one another. This regularity allows of conclusions regarding the presence of one or several fracturing forces.

2. Injuries to the brain from blunt violence.

a. Facts.

Prescott Hewett (1858) also had statistics over injuries to the brain, based on 69 cases of his own and a number of cases from the literature. His survey covers all main types of cerebral injury. He stated that the vast majority of the cases showed only focal injuries, while only isolated cases displayed diffusely spread haemorrhages. The focal injuries favour in their turn certain definite parts of the brain. It is most usual to find injuries on the surface, either immediately under the site of violence or at the point diametrically opposite. In the deeper parts of the brain (away from the surface) injuries are similarly found in patches deep in the white matter, in the basal ganglia, or in the pons. In the cerebellum the injuries are for the most part found on the under surface of the lobes. Certain parts of the cerebrum, too, are hit much more often than others, and here, too, we find that 'the under part is very much more frequently bruised than any other ... Sometimes limited to a few patches of contusion, the injury much more commonly extends over the whole surface of a lobe, and oftentimes of two lobes at once'. As in other organs, there are different degrees of contusion in the brain. In the milder cases we see only small streaks of haemorrhage close to one another, densest in the middle of the injury and thinning out towards the edges, all within the gray matter. In more serious cases, 'the central parts of the bruised portion, thoroughly infiltrated with blood, are of a uniform, dark purplish colour, which extends some distance both into the grey and white substances: imbedded in this part are little clots of blood of the size of peas, and around the circumference and in the deeper parts are specks of extravasation scattered more and more widely until they gradually disappear. The brain-substance torn, broken up, and shreddy, readily gives way under a gentle stream of water which, gradually loosening the clots of blood, carries them away, leaving little pits

with irregular and shaggy margins, and thickly studded throughout with pinpoint extravasations'. The deep haemorrhages are either groups of small, rounded bleedings, or have merged to form larger patches. Hewett made a number of observations regarding the connexion between different injuries, and quoted cases with cerebral injury only under the point of impact, only at the opposite pole, and at both poles simultaneously. 'Contusion of the brain is, however, rarely thus limited to the region where the blow was struck, except in cases where the bone has been driven down. In fissure of the skull, you will find that it happens much more frequently that the bruised part of the brain is far away, and directly opposite to the seat of the blow'. Concerning the different parts of the base of the cerebrum, he reports that 'the posterior lobes are rarely injured — the anterior ones very frequently — and the middle lobes the most frequently of all'.

In the literature following, there are on the whole very few new facts apart from what Hewett submitted:
1) By way of introduction, Martland and Beling (1929) classified their 309 cases according to fracture, and to cerebral injury at the site of violence and the point directly opposite respectively (see tab.). This classification showed that the correlation between the incidence of these types of cerebral injury is negative, a fact, however, which these two authors do not follow up. Esser (1936) gave a survey of the connexion between the localization of the violence on the skull and the occurrence and extent of the injuries at the site of impact and the opposite point; this is given in table form below (see tab.). Esser stated that his material can only be used for a preliminary survey, and urged rising investigators to further research. The fact that there is no direct connexion between the occurrence and the magnitude of the injuries at the site of impact and the point directly opposite has been pointed out by a number of scientists (Lenggenhager, 1936 and 1938, Kraemer, 1937, Franz, 1939, and Kalbfleisch, 1940). Many are the observations of cases with no injury at all at the site of the blow, while greater or lesser contre-coup injuries are to be found. Kalbfleisch emphasized the fact that these latter are usually greater than those at the site of the blow. Franz issued an enquiry among 'Berliner und auswärtigen Pathologen» as to whether the brain was usually uninjured at the site of impact (in blunt

Esser (1933): *The connexion between the localization of violence on the skull and the type of the injuries to the brain.*

Site of violence over	Impact-pole injury		Opposite-pole injury	
	Frequency	Size	Frequency	Size
Os frontale	Often missing	Small to large	Often missing	Small
Os parietale	Most often present	Small	Missing only as an exception	No data
Os temporale	Always present (in fracture)	Quite large	Missing only as an exception. In addition there are often injuries in the interior of the brain	Moderate haemorrhages
Os occipitale	Missing. In addition is observed 'gelegentlich Einklemmung eines schmalen Kleinhirnstreifens' between the edges of the fracture		Always present	In some few cases small, but usually 'schwere bis schwerste'

No regard is paid to the incidence of fracture. Figures not given.

Martland & Beling (1929): *The correlation between skull fracture and different brain injuries, and the relation of the latter to one another.*

	Impact-pole injury	No impact-pole injury	Opposite-pole injury	No opposite-pole injury	Total
Fracture	74	192	196	70	266
No fracture	3	10	11	2	13
Total	77	202	207	72	279

			Total
Opposite-pole injury	30	187	217
No opposite injury	50	36	86
Total	80	223	303

In addition: No data as to fracture 24
Error in the table 6

$r = -0.453 \pm 0.046$

violence.) The answers he got varied greatly, and he, too, appeals to coming scientists.

2) Le Count and Apfelbach (1920) submitted a material of 504 autopsy cases, and observed that contre-coup injuries only result from a blow when the head is free to move (at a 'free head') (in 40 cases with violence to a supported head, no such injury was observed).

3) A number of more recent works have touched on the problem of the traumatic haemorrhages in the interior of the brain. Schwarzacher (1924) communicated 7 cases of his own, which are, however, apparently great injuries from the surface downwards, mainly at the point opposite the blow. These injuries occur primarily among older persons, and in certain traumata. Reuter (1927) had also 7 cases of his own, but these show really central bleeding. This also occurs most in the aged, and always in the direction of the blow. Cassasa (1924) showed 5 cases (of many thousands), where the bleeding was of purpuric type. In a number of works, Berner (1930—1936) has pointed out multiple haemorrhages of varying extent, sometimes only visible microscopically, under the anterior part of the fourth ventricle and round the aqueductus Sylvii and the third ventricle; in addition, in the deeper parts of the pons and in the basal ganglia. In his later works Berner showed that these were diapedesis bleedings, and that haemorrhages may occur at these places — particularly in the floor of the fourth ventricle — in intoxications and diseases also. Polemizing against Berner, Harbitz maintained in a number of writings (e. g. 1934 and 1939) that such haemorrhages are, practically speaking, always — which would then cover Berner's material, too — found in connexion with other and greater injuries to the brain. In his own material (117 + 157 cases) deep haemorrhages of this sort never occurred in connexion with violence, which gave a limited depression fracture, as, for example, 'Totschlag mit einem Beil, Hammer u. s. w.' This can explain why the deep haemorrhages have with time become more and more usual in his medico-legal autopsy material. Earlier on, this type of fatal violence was most common; latterly, highway accidents have been behind most of the post-mortems. Martland and Beling (1929) also observed that deep haemorrhages practically never attend fractures of the vault. Neugebauer (1937) can be said to confirm

the findings of both Berner and Harbitz. In 44 cases, 'Berner haemorrhages' were established. As far as could be seen from the available knowledge of the clinical course (in 13 cases) the persons concerned had displayed concussion, and all were seen to have numerous other cerebral or non-cerebral injuries or diseases. A control material of 6 cases showed neither Berner haemorrhages nor concussion (except one doubtful case with fat-emboli).

4) Wolff (1932 and 1936) has made valuable contributions to our knowledge of cerebral injuries, although the problem he approached was the haemorrhage mechanism in the brain substance. He divides the haemorrhages into three groups: 1) Trümmerblutungen, 2) Perivasculäre Raumblutungen, and 3) Kugel- oder Ringblutungen. The first-mentioned need no further explanation, as they are set up round mechanically ragged brain substance. The perivascular haemorrhages occur mainly in the cortex of the cerebrum, but may also continue along the vessels penetrating down into the white matter. The haemorrhages appear as an immediate result of the trauma, and, for the problems of this thesis, Wolff's exposition of the successively appearing tissue reactions are of no very great interest. Sphere and ring haemorrhages ('Kugel- und Ringblutungen') are set up for the most part round capillaries, but are also found round larger vessels, 'allerdings fast nur in Marksubstanz'. It is the tissue structure that determines this type of haemorrhage, and they occur in a number of different conditions, including post-traumatic. It is generally agreed that they are diapedesis bleedings. They are of reactive character, as a result of different types of hurt. The great advantage in post-traumatic bleedings of this kind is that the infliction of the injury is instantaneous and temporally determined. By using this fact, Wolff made out the development of sphere and ring haemorrhages: Immediately after the trauma no such bleeding is seen; after two hours bleeding that might be sphere haemorrhage sets in, after five hours definite sphere haemorrhage; after ten hours small ring haemorrhages appear for the first time. A great many large ring haemorrhages are seen in persons who died 12—24 hours after the accident; cases investigated still later (2—8 days after the accident) display only cellular reactions from

surrounding tissue: the specific type of the haemorrhages is not changed.

Esser's investigation (1933 a) into injuries to the cortex and their healing stages confirmed Wolff's results as regards the earlier stages. Esser made the remarkable discovery that the molecular layer of the cortex is free from haemorrhage, and that it keeps its structure even after the haemorrhage foci have been completely reabsorbed.

b. **Theories.**

Hewett (1858) accepted the old theory of contre-coup, and further agreed with Brodie (1828) that 'the great irregularities which exist in the inner surface of the basis of the cranium sufficiently explain wherefore the inferior is more liable to be ruptured than the superior surface of the brain'. The slight injuries to the posterior lobe of the cerebrum can be explained by saying that this lobe rests on the soft tentorium.

In the subsequent discussion, quite a number of authors accepted the idea that injuries at the point opposite the blow result in this way from a supposed hard collision of the cortex with the skull. Kocher (1901) tried to explain the fact that the cortex is often uninjured at the site of impact but badly injured at the diametrically opposite point by assuming that, at the former place, the cortex only encounters resistance from the underlying soft white matter, whereas at the latter place it encounters the hard wall. (This assumption does not hold water, since the cortex at the site of impact is hit by a surface just as hard as the one it encounters at the opposite point). Tilmann (1902) tested the course of an impact on a free sphere of gelatin: A blow on one spot releases a wave motion which collects at the diametrically opposite point and makes this rise from the centre. He assumed this would happen in the brain, also, and produce the limited injuries at the opposite point. (He did not take into account, then, that the course of an impact in a soft mass enclosed in a hard shell will be quite different, being determined by the shell's properties). He emphasized the difference in principle between force to the free head and force to the supported head, and showed this in experiments where he aimed blows at the trephined heads of cadavera, some in the neighbourhood of the trephination, some

opposite it. Blows on the free head in both cases ejected the brain substance through the trephination; this was not so when the head was held firmly in place. This ejection was immediate in blows near the trephination; in blows opposite it, an interval of time was required, and greater energy in the blow.

Various authors have discussed the wave motions that may be conceived to take place in the skull contents, in order further to elucidate and attempt to explain the contre-coup injuries. Doepfner (1912) mentioned this possibility and experimented with manometers inserted in the brains of cadavera, but got no results. He retained the view of Kocher that the blow was transmitted through the brain on the whole rectilinearly, and caused injuries at the opposite point and in the interior at borders between different media, e. g. in the ventricle walls. Genewein (1918—1923), supported by his investigations into gunshot injuries which are discussed here later, wanted to prove that the brain is in physical respects to be regarded as a solid body and that it therefore (!) transmits the impact only rectilinearly. Schwarzacher (1924) carried out the following experiment to explain the 'traumatische Markblutungen' he observed: A skull was emptied of its content and filled with a transparent gelatin, after which two diametrically opposite trephinations were tightly closed with glass windows. Through these windows it was possible in polarized light to see the changes of stress (impact waves) set up by striking the preparation with a hammer. He observed a swiftly running wave at right angles to the direction of the impact and proportionate to its strength, and also one or more 'minder hell erscheinende, sich oft überkreuzende Sekundärwellen das Gesichtsfelt durcheilen'. (There could not, of course, be any question of a detailed analysis of the rapid courses with the naked eye). The viewpoints were taken further (without experiments of their own) by Hellenthal (1933) and Kalbfleisch (1940). The latter pointed out, very rightly, that to take the injuries at the point opposite the blow as a counter-stroke 'setzt voraus, dass sich das Gehirn physikalisch wie ein fester Körper verhält'. Backed up by the observation that the injuries at the point opposite the blow are as a rule more extensive than those at the point of impact, he subscribed to Kocher's view that the impact spreads out conically, and goes on to say: 'Von der Grösse der Stossfläche hängt die Grösse des

Durchmessers des Kegels ab und damit die Ausdehnung der von den Stosswellen durchflossenen Hirnteile. Bei breiter Auftreffstelle der Gewalt wird also ein ausgedehnteres Hirngebiet getroffen'. (This conflicts directly with experience: For one thing there is no certain connexion between the extent of the injuries at the impact pole and at the point opposite; also, as the skull is curved in form, the striking surface is, practically speaking, the same size in all violence, at any rate in plane violence, and this would thus mean that all contre-coup injuries should be, generally speaking, equally extended).

Assuming a real counter-stroke, Spatz (1931—1936) has tried to explain the predilection of the injuries at the opposite pole for the tips of the frontal, temporal, and occipital lobes by the fact that the layer of cerebrospinal fluid at this places is thinner than over the other parts of the brain. For this fluid should lie as a pad between the cortex and the bony wall and soften blows. (In the following pages, an entirely different explanation of this fact will be given).

As has already been mentioned, Duret (1878) thought that, in blows to the skull, a 'cone de dépression' was formed at the impact pole, and a 'cone de soulèvement' at the point opposite. With this as starting-point he then explained the brain injuries arising, and this is two ways. 1) The depressed part of the skull must of course squeeze its content to one side. Duret thought this to be done by the cerebrum's being compressed and thereby emptying the cerebrospinal fluid out of the lateral ventricles, this fluid then continuing the natural way through the aqueductus Sylvii and the fourth ventricle out into the large cisterns at the basis. The violent flow of fluid would cause injuries to the walls in the narrow place in the aqueduct, and the rapid jet from the acqueduct set up injuries to the walls in the fourth ventricle. 2) The injuries at the point opposite the blow is on the other hand explained by a violent rush of cerebrospinal fluid on account of the vacuum that must be supposed to result below the 'cone de soulèvement'. In analogy with this, the injuries at the point of impact were explained by the pressure below atmospheric which can be expected when the 'cone de dépression' subsides after the blow. Injuries to the brain surface in those parts facing the base of the skull were not, on the other hand, explained in this way

since the vertebral column would prevent a 'cone de soulèvement' forming in this portion. Here Duret took instead the continued action ('une brusque inondation') of the flow of fluid from the ventrical system, Duret's choc céphalo-rachidien. (Duret's explanations suffer, needless to say, from the contradiction that some injuries are due to pressure above atmospheric, others to pressure below atmospheric, nor, as the following will show, have his views been spared a great deal of criticism).

Duret's second explanation can thus be applied mainly to injuries of the cerebrum's surface, and many authors have in the subsequent discussion taken precisely a pressure below atmospheric as the right explanation. As we know, the previously mentioned works by Braquehaye (1895) and Chipault and Braquehaye (1895) have shown experimentally that such pressure below atmospheric is set up initially in their 'zone de soulèvement' and secondarily over the whole cerebral surface alternating with pressure above atmospheric. As, however, their registering devices showed greater deflection for pressure above atmospheric (primary or secondary), the findings were interpreted as showing pressure above atmospheric to cause the visible injuries. (The experimental insertion of a fairly large, soft rubber diaphragm in a trephination produces such a change in the course of the impact that we are not justified in taking into account anything more than just the initial phase. In addition, the mechanical transmission probably means that regard can only be paid to the direction of the deflection, not to its extent). Rawling (1904) and Schwarzacher (1924) rejected Duret's views as 'erroneous suppositions' and 'phantastische Vorstellungen' respectively. Russell (1932) explained the injuries at the point opposite the impact as due to the inertia of the brain: when struck it continues its movement — and remains at rest respectively — because its specific gravity is greater than that of the cerebrospinal fluid. As a result of this, the subarachoid space would be expanded at the point opposite impact, and the small vessels that run at right angles from the pia in towards the surface of the brain are torn off. He also says that the haemorrhages primarily set in just in the subarachnoid space and subsequently, in greater injuries, penetrate the brain substance. (This statement, which is a necessary consequence of the view in question, is nevertheless erroneous, as Goggio (1941) pointed out). Lenggen-

hager (1936 and 1938) seized upon the similarity with the course of impact in a solid body. When the impact wave reaches the free end, the particles here attempt to continue in the direction of the wave, and if the cohesion of the material is not sufficient, particles are thrown off from this end ('Abschleuderung'). In order for this to hold for the injuries at the opposite pole of the brain, however, there must be a free space into which the particles can be thrown. This is set up according to Lenggenhager by the intracranial pressure changes occurring at the impact: at the site of the blow there is 'eine enorme Drucksteigerung'. This presses blood and cerebrospinal fluid out of the cranial cavity, and a vacuum is set up at the opposite pole. Even with no vacuum, bleeding at the opposite pole could be explained as 'Sogblutungen' through a pressure below atmospheric that does not get as far as a vacuum. In this case, then, the other mechanism ('Abschleuderung') drops out. (Actually, therefore, this mechanism seems superfluous, since the haemorrhages can be explained only by pressure below atmospheric, and such explanations have, as been mentioned, been offered earlier on. We can further, with Franz (1939) question whether blood and fluid really have time to stream out of the cranial cavity in the short time the impact lasts). As well, Lenggenhager did not want to apply his view other than 'bei unversehrter Schädelkapsel', which Franz rightly criticized. Finally, Goggio (1941) advanced 'the pressure gradient theory' to explain the contre-coup injuries. He regarded the skull as a rigid shell, filled with the semi-fluid brain substance which is connected with the outer world by the foramen magnum and the foramina jugularia. When a system of this kind is retarded or accelerated by an impact, a pressure in the contents is set up which acts during the time the impact lasts (against the direction of the impact). (The pressure is assumed to be constant during the whole time of the impact). According to the rules of hydrostatic pressure, this pressure must be greatest at the site of violence and decrease successively in direct proportion to the distance ('pressure gradient') towards the opposite pole, where it is least. The absolute pressure will depend on the plane (at right angles to the axis) which is exposed to the outer world, and therefore assumes the outer pressure, in this case the plane through the foramen magnum. Between the point of impact and this plane

there is pressure above atmospheric, at the opposite pole pressure below atmospheric. Violence to the occiput, therefore, gives the lowest absolute pressure below atmospheric, which can explain why the contre-coup injuries are most common in such violence. The haemorrhages are set up because 'the small blood vessels in the area of contre-coup are distended and ruptured by a sudden release of external pressure which is not completely met by a fall in intravascular pressure due to circulatory inflow from an outside pressure source, the contraction of the left ventricle of the heart'. (Against the view it can, as against Lenggenhager's, be said that, during the short period the impact lasts, there is no time for the supposed displacement: 1) The levelling-out of pressure in the form of a flood of cerebrospinal fluid through the foramen magnum and of blood through the jugular veins, and 2) the harmful overfullness of blood in the small vessels within the contre-coup area. In his example, Goggio reckons the impact to last 0.1 second. For comparison it may be mentioned that the times found by the author on a model the size of the skull are 0.003—0.004 seconds. The same remark then also applies to the assumed, constant distribution of pressure determined by hydrostatic rules. Further, no regard is paid to the cranial deformations which *do* have time both to develop and to subside during this time.)

Duret's first mechanism (le choc céphalo-rachidien) has also met with contradiction in the subsequent discussion. Tilanus and Deucher (Kocher's school) showed by experiments on dogs from which the cerebrospinal fluid had been drained that the same effects can be produced after traumata. Kolisko (1911) maintained that the mechanism in question is physically impossible, since the cerebrospinal fluid and the brain are as *one* fluid content, and Harbitz (1934) agreed with this: An increase of pressure spreads in accordance to hydrostatic rules equally in all directions within the cerebrospinal fluid and the brain. To explain his findings of purpuric bleedings, Cassasa (1924) nevertheless submitted a view in close accordance with the Duret choc: When the pressure is increased, the blow drives the cerebrospinal fluid into the perivascular spaces and stretches the fine vascular branches beyond breaking point. Martland and Beling (1929) take up this view on their own account. In a number of works (1930—1936)

Berner has pointed out the occurrence of bleedings in the brain stem near the ventrical system. In the earlier works he accepted the choc céphalo-rachidien as explanation, but in the later ones he states both that such bleedings are also present in intoxications and diseases, and that they do not agree in type with the ones experimentally presented by Duret. That is to say, the latter are usually situated posteriorly in the fourth ventricle and have the character of rhexis bleedings from lacerations in the ventricle wall, whereas Berner's bleedings lie in front of the striae acusticae, under uninjured ependyma, and are diapedestic in character. Dahl (1937 and 1938) aimed to show with his pathological and experimental investigations that Berner's bleedings are agonal and independent of trauma; Eck (1940) agreed with this. (Even if, as Berner himself showed, these bleedings can set in without trauma, it cannot be denied that in many cases they really have a direct traumatic nature. Harbitz (1934 and 1939) gave an incontestable support to this by his observation that these bleedings often occur in severe injuries to skull and brain, but never in combination with limited depression fractures in the vault).

3. **The concussion problem from a physical viewpoint.**

Gama (1835) carried out a number of experiments which seemed to confirm the classical view that unconsciousness was due to oscillation of the brain. He stretched a number of threads in different directions in a retort, and filled the latter with a gelatin solution which, on congealing, had about the same consistency as the brain. When the retort was struck with the hand or with different instruments the mass oscillated in proportion to the strength of the blow. Gentle blows showed oscillation only near the place struck. When the blows were harder, it could be seen how the whole content shook, and, as well, how the gelatine mass immediately came away from the walls of the retort both at the place struck and at a point opposite. It afterwards rapidly resumed its old position, and it could not with certainty be made out whether the procedure was repeated less markedly. Alquié (1865) tried in vain to repeat these experiments. If the retort really was quite filled and closed, no movements were observed. Instead he studied the brain of cadavera and living animals

through a trephination. No vibrations were observed from blows; what was seen was that the brain moved as a whole. In the discussion following, these experiments have been regarded as definitely disproving the vibration theory. (In and with the openings made in trephination, Alquié's experiments suffer from the same mistake as he himself pointed out in those of Gama). Decisive for this question are Schwarzacher's (1924) direct observations of intercranial impact waves.

Duret (1878) wanted to explain unconsciousness as a result of his choc: He thought the onrushing fluid masses in the ventrical system released from the corpora restiformia a reflectory vascular cramp in the brain. (This possibility is questioned from a physiological viewpoint, too, e. g. by Tilanus and Deucher). A view closely associated with Duret and Cassasa was advanced by Dixon (1940): Unconsciousness is conditioned by cerebrospinal fluid having been pressed out of the perineural and perivascular spaces, so that the nerve cells are deprived of their means of nourishment. This state lasts until the fluid has streamed back again. (This view is, of course, wrong, for the same reasons as were raised against that of Duret).

Supported by the theory of the 'cone de dépression', the Kocher school worked out its theory of the acute brain pressure: 'die Hirnpressung'. They built, that is to say, on the view that the volume of the skull is decreased under the influence of the trauma, and therefore the blood stream is checked, the brain substance is rendered anaemic, and unconsciousness is mainly due to this anaemia. See Kocher (1901). (Against this the objection can be raised that it has not been shown whether the volume of the skull really does get less — cf. Thoma (1909) — and that it is highly doubtful if anaemia can give unconsciousness as instantaneously setting in and of so long duration as that which characterizes concussion. These physiological viewpoints are advanced *inter alii* by Miller (1927) and Russell (1932).)

Tilmann (1899) seized upon the fact that unconsciousness results from a fall to the ground and, with the exceptions mentioned below, after blows to an unsupported head, but not from violence to a supported head or blows where, though the head is unsupported, the striking surface is so limited and the velocity so great that a limited depression fracture is produced. He stated,

thus, that unconsciousness sets in only when the motion of the head is changed (accelerated or retarded). This develops reactive forces on account of the inertia, and these are proportional to the density. As the acceleration shock is very great, even small differences in specific gravity can mean large (absolute) differences in force, and be thought to produce displacements between parts within the cranial cavity of different specific gravity. Tilmann submits the following specific gravities:

Gray matter	1.020—1.024
White matter	1.027—1.029
Blood	1.055
Cerebrospinal fluid	1.008

The following displacements are calculated to arise:

1) The brain as a whole is pushed towards the site of impact, while the cerebrospinal fluid is driven out of the way. This softens the impact of the brain against the bony wall.
2) Cortex and white matter are mutually displaced, the white matter towards the point of violence and the cortex towards the diametrically opposite point.
3) The blood in the vessels is urged towards the point of violence and can therefore burst the capillaries, particularly in the cortex, whose specific gravity is less, and which is looser in consistency.

Supported by the same viewpoints, Rahm (1920) asserted that intracellular displacements, too, could set in, as 'innerhalb der Ganglien-zellen wirklich Stoffe verschiedenen spezifischen Gewichtes vorhanden sind', e. g. lipoids, lighter than water. Otherwise, Rahm's work contains nothing essentially new. (There is nothing to object to, from a physical point of view, in Tilmann's and Rahm's deductions, reviewed here. The question is, nevertheless, whether these different types of displacements with the small differences in specific gravity and the short time we are concerned with here can be large enough to give a physiological effect. For no anatomically discernible injuries arise intracellularly or between cortex and white matter, and Tilmann's third mechanism cannot explain why bleedings in the brain form in patches. As the present author's work only deals with the visible injuries, these theories can be left out of account).

Berner and Neugebauer (loc. cit.) tried to see the anatomical background of the unconsciousness in the small haemorrhages round the fourth ventricle. Harbitz, Dahl and Eck (loc. cit.) did not share this view; the two lastmentioned did not even want to derive these haemorrhages from trauma at all. The solution of the problem may well be found in Harbitz's observation that such haemorrhages occur in connexion with other injuries resulting from the type of violence giving concussion (cf. Tilmann, 1899).

4. Gunshot injuries.

a. Facts.

It has long been known (v. Bergmann 1880 b.) that a projectile hitting the skull gives round (or oval, depending on the direction of the projectile), limited fractures, 'Lochfrakturen'. If the projectile has sufficient kinetic energy to pass right through the skull, a similar fracture is obtained at the place where it passes out. It has also been known from of old that the hole in the bone lamella which is hit first is, as it were, stamped out and corresponds exactly to the calibre of the projectile, whereas it broadens in the diploë and is largest in the bone lamella hit last (the lamina interna at the entrance and the lamina externa at the exit respectively). Projectiles with little kinetic energy, which are not able to go right through the bone, can set up isolated fractures in the bone lamella furthest from the projectile. (Teevan 1865, Rücker 1881).

The development of modern firearms and the accompanying ever-increasing projectile velocity produced, during the last half of the 19th century, experiences of new types of bone injuries from gunshots. In the first place limited fractures, at some distance from the points of entrance and exit, were observed within the thinnest parts of the base of the skull, above all in the orbital roof, but also in the lamina cribrosa and the roof of the middle ear. (Longmore 1865, v. Bergmann 1880 a, Rücker 1881, Chipault and Braquehaye 1895, W. Ipsen 1898, Stierlin 1900, Tilmann 1902, and others). The fractures of the orbital roof show regularly a dislocation out from the cavum cranii and down into the tissues of the orbit. Secondly, a more or less pronounced explosive effect

on the skull as a whole was obtained. From either or both of the wounds bone fissures, going right through the bones of the skull, proceed irregularly in different directions, and in the most serious cases the skull proves to be splintered into numerous, small, irregular fragments. (Holst 1865, Busch 1874, Heppner and Garfinkel 1874, Kocher 1875, v. Coler and Schjerning 1894, Chavigny and Gelma 1923, Biancalani and Costa 1928). Tilmann (1898) observed that these fragments are only firmly attached to the scalp by their central portions, while at the periphery they hung loose.

Krönlein (1899) observed for the first time the type of very severe gunshot injury which has subsequently been given his name ('Krönlein-Geschüsse') (Henne 1900, Franz 1908 and 1910, and others.) What is characteristic of these is that both skull and scalp are lacerated, and that the whole or half of the cerebrum, practically uninjured, has been thrown out of the cranium and is found at a greater or smaller distance from the injured (killed) man.

Within the brain substance the penetrating projectile produces a canal or track surrounded by ragged brain substance and haemorrhages. The details in the appearance of the brain injury do not seem to have been subjected to any very close investigation in older times. Klebs (1872) described six cases of fatal gunshot injuries. Two of these showed bullet canals through the brain with completely smooth walls without haemorrhage, and have for that reason roused attention in the subsequent discussion. Both cases had to do with small projectiles (splinters of rifle-bullets) which did not explode the skull.

The largest investigation we have in this field is that of Genewein (1918). He found the actual bullet canal in the brain substance to be considerably wider than the bullet's calibre; thus, in shot with a calibre of 8 mm, it was in one case 25 mm, in another 18 mm at the entrance and 16 mm at the exit, and in shrapnel shot with a calibre of 13 mm a canal 18 mm in diameter. Round it there was a narrow, completely necrosed border zone, and outside that a zone of very fluctuating width, where the tissue shows bleedings and, in a microscopic examination, more or less marked necrobiotic signs. Peripheral to this the brain substance shows neither macroscopic nor microscopic changes, apart from

the small haemorrhages or crushed portions which could be seen in association with the previously mentioned indirect fractures (that is to say, mainly on the under sides of the frontal lobes, above the orbital roof fractures) (Spatz, 1941).

b. **Experiments.**

Both the ballistic (see Cranz 1917) and the medical literature contain numerous contributions to illustrate by experiment the effects of shot in general, and such effects on skull and brain.

Shots through solid plates always give perforation with, in principle, the same appearance as described above regarding the bones of the skull (Kocher 1895, Schumacher 1909): a hole in the surface first hit corresponding to the calibre of the projectile. The hole then widens conically right out to the further surface. Not until the velocity of the projectile is very greatly lowered do the plates used break, corresponding to what happens, for example, in blows from a hammer.

Shots through soft masses (clay) (Heppner and Garfinkel 1874, Kocher 1895, Hildebrandt 1904; see further Cranz 1917) always give canals that are appreciably wider than the calibre, and of different shape, depending respectively on the shape of the mass shot at and the mass, calibre, and velocity of the projectile. The canals through plates of clay spread out in the shape of a funnel in both directions and the borders are thrust outwards. Canals through larger blocks of clay show on the other hand a spool-shaped widening in the middle, and in these cases the borders of the entrance hole are thrust inwards. Rapidly taken series of 'moment (sparkle) photographs' show in these cases how the clay particles are first thrown out through the entrance hole (in the opposite direction to that of the shot), and are then sucked in again towards and into the entrance, so-called 'Afterwirkung' (Thiel 1903). Shots at round lumps of clay blow them altogether to pieces, as long as they are less than a certain size; large lumps show a canal of the same type as was described for the large blocks.

Empty vessels are of course perforated in the same way as solid plates. Vessels with fluid or soft content show an explosive effect of the same type as the skull, whether they are quite full

or partly full, and closed; or open (Busch 1874, v. Coler and Schjerning 1894, Bircher 1915).

Heppner and Garfinkel (1874) shot at skulls filled with clay. Shots from light arms gave them typical holes at entrance and exit through the bones, and a track through the clay wider than the calibre, with its diameter getting less towards the exit. Heavier arms blew the skull completely to pieces and the clay particles were thrown out in all directions. Tilmann (1898) shot at 'Vollschädel', and always got a spool-shaped canal wider than the calibre, surrounded by 'krümeligen Hirnbrei'. From the canal could sometimes be seen fissures radiating out as far as the surface of the brain (in the depth of a sulcus). When the shot had passed near the (soft) basal ganglia, the raggedness within these extended considerably further outwards than within the white matter. Shots at living dogs showed the same picture, and in addition a surrounding zone with haemorrhages in the form of dots. All the experimenters agree that shots at an empty skull never give an explosive effect, but only typical entrance and exit holes (Busch 1874, Kocher 1875, v. Coler and Schjerning 1894, and others).

Cinematographic records of shots through a Vollschädel (Tilmann 1898), and series of moment photographs (Cranz and Koch 1900), show that the explosive effect does not take place until the bullet has passed out the other side, and that the blowing of particles in all directions continues for a certain time afterwards. On Tilmann's series of pictures, the skull is clearly seen to expand in all directions, and afterwards (plainly under the influence of the uninjured skin's elasticity) to contract again.

c. Theories.

The conical form of the shot fractures has produced several different attempts at explanation. von Bergmann (1880 b) considered this form due to the fact that the projectile takes with it fragments from the layers nearer the surface and therefore has a greater calibre when it passes the deeper ones. The same explanation was advanced, independent of the earlier discussion, by Piédelièvre, Desoille and Herisset (1939). Paltauf (1888) found the same fracture form caused by other instruments with small, sharply demarcated striking surface. The fractures had this form,

he thought, because the inner cohesion in the lamina vitrea is greater than in the substantia spongiosa, and advanced 'die Thatsache, dass mit Dicke und Zartheit der Spongiosa und Stärke der Glastafel die Abschrägung wächst'. (It can be argued against these views that the same form is yielded by shot through homogeneous plates, and that non-penetrating shots, 'Prellschüsse', also give fractures in the lamina interna that are far greater than the calibre). Schroen (1902) applied his special impact physics to these forms of fracture also. (As has already been said, his calculations are much too simplified and lead in part to obviously unnatural results. This also holds of this fracture form, when he assumed in boundary-line cases at a very high velocity that a cylindrical piece is stamped out). In his calculations, Ipsen (1906 and 1925) started out from the deformation in bilateral pressure and introduced forces acting at right angles to the direction of the shot, whose resultants together with the pressure acting in the direction of the shot were to give an oblique force co-inciding in direction with the slope of the conical surface. (As the pressure in blows and shots is unilateral, a construction of this kind is impossible, and if one really had a bilateral pressure, it would even so be possible according to Ipsen's scheme to explain the fractures having a conical form turned in the other direction). H. and C. Marx (1908) and Schumacher (1909) made independent explanations of the shot fractures with application of the rules and terms of the theory of elasticity. H. and C. Marx proceeded from the different stresses arising where the vault is hit, namely:

1) Stresses parallel with the surface. a. Radial. b. Ring-shaped. They may be stress either of pressure, pulling, or bending, (i. e. opposite direction in the outer and inner layer of the bone).
2) Stresses at right angles to the surface, so-called shearing stress.
3) 'Oberflächenspannungen' (not taken into account in the subsequent deductions).

In shots, the stresses in the vault are restricted round the entrance hole, as they need time to spread like 'durch einen Steinwurf erzeugte Wellenbewegung des Wassers'. The hole in the bone lamella hit first is due to the fact that the shearing strain exceeds breaking-point. The probability of such breaks is increased with

the kinetic energy of the instrument, and with a diminishing size of the striking surface. The conical form is due to tensile stress in the deeper layers. Schumacher's work begins with a theory for the elastic impact. The primary longitudinal impact wave is, however, assumed to subside very quickly within the colliding objects. Hole fractures may occur either in suitably supported plates or with so high a velocity in the collision that the inertia of the masses constitutes sufficient support. He made numerous experiments with stamping out of plates of different materials, and always got conically widened holes. The details in the form of the cone depend on the properties of the perforated material. Thus a hard compact material gives an evenly expanded surface (e. g. glass and compact bone), a porous material begins with an almost cylindrical, compressed part, and does not expand until later (e. g. plaster of Paris or spongy bone), and a lamellar material gives a surface extended in the form of steps (e. g. slate). The conical shape is due to the fact that the layer first hit is pierced by shearing, and that an oblique deflection of the shearing in all directions is set up in the following layers, on account of the compressed particles being squeezed not only downwards but also towards the sides. When this deflection has reached a certain extent there are (as H. and C. Marx also maintained) tensile and bending stresses in the deepest layers. Shot fractures arise in the same way as these stamped-out hole fractures. 'Nur der Einfluss der 3 Schichten auf die Bruchform machte sich bei den Lochschüssen weniger geltend; ferner war im Verhältnis zum Geschosskaliber resp. zum Bolzendurchmesser die trichterförmige Zunahme des Defektes bei den Schüssen stets viel kleiner als bei den Durchschlagungen, was sich beides aus der Kürze der Gewalteinwirkung erklärt. (Noch grösser war dieser Unterschied bei den Glasplattenversuchen) ... Zweier Punkte müssen wir noch Erwähnung thun, es ist dies die (meist) grosse Geschwindigkeit der Geschosse moderner Handfeuerwaffen und ihre ogivale resp. runde Gestalt. Für das Zustandekommen der typischen Trichterform des verursachten Defektes sprechen wir ihnen jede wesentliche Bedeutung ab. Die Geschwindigkeit ist von Einfluss auf die Steilheit der Bruchkurve; je schneller das Geschoss durchdringt, umso geringer ist die Abflachung gegen den Ausschuss'.

The isolated fractures in the bone lamella furthest from the

projectile were taken up for treatment by Teevan (1865). Earlier on, in the discussion fully reviewed by Teevan, only isolated fractures in the lamina interna had been observed; they were explained as due to the fact that this lamella was more brittle (hence the name lamina vitrea). Teevan showed, however, that violence from the inner side gave isolated fractures in the tabula externa. The explanation is that the limited deformation of the bone resulting from this type of violence gives compressive stress on the side hit and tensile stress on the other, and that the resistance of the bone substance to pulling is less than that to pushing. Paltauf (1888) found the same fracture types from blunt objects with restricted (shaped) striking surface. The fracture in the lamina interna (the force acting from outside) was always more extensive than the striking surface.

Various opinions have been advanced as to the indirect shot fractures. Longmore (1865) explained the fracture of the orbital roof by the impact of the brain against the inside of the skull. Busch (1874) made numerous experiments as to the explosive effect and advanced three possibilities by way of explanation: 1) The scattering of fused or splintered particles of the projectile in all directions. 2) The centrifugal force on account of the bullet's rotation. 3) The hydraulic pressure. Kocher (1880) showed that the first possibilities cannot have any importance for the explosive effect; the small splinters of lead were shown to have so little kinetic energy that they could not penetrate a sheet of paper, and projectiles without rotation (out of a smooth barrel) gave an explosive effect. There only remains therefore, according to Kocher, the hydrostatic action ('Seitenwirkung'). In this rather older literature, this action may well really have been taken as hydraulic in the same sense as the action in the hydraulic press, i. e. that the projectile had the effect of a piston in the entrance hole. It was therefore of great importance when von Coler and Schjerning (1894) were able to show not only the hole at the entrance but also that at the exit on an exploded carefully reassembled skull. The explosion could therefore not have taken place before the projectile had again left the skull. The explosive effect was explained to be of hydrodynamic, not of hydraulic nature, in the sense that the projectile on its way through the soft brain substance forces it out of the way in all directions, and thereby,

with loss of its own kinetic energy, gives to the particles of the mass an acceleration outwards in all directions. They also showed, in accordance with their theory, the explosive effect through liquid in an open vessel. Braquehaye (1895) also tried to register the changes in pressure in shots through the head with the help of his previously described device for measuring pressure. The action was so strong, however, that the membrane of the registering capsule was burst and the brain substance spurted far out into the manometer tube.

In spite of the overwhelming evidence a number of authors have rejected the theory of the hydrodynamic action. Although von Bergmann (1880 a) was inclined to accept the explosive effect as the explanation to his cases of fractures to the orbital roof, he took a more critical attitude in his part of Deutsche Chirurgie (1880 b). If the orbital roof fractures are due to an explosive effect through the brain, much greater cerebral injuries should result, and such shots ought to be immediately fatal. This is, however, not the case, and these fractures were taken to be incomplete bending or breaking fractures. In an earlier work (1888) H. Bircher shared this view, but in his later works (1896) he went over to an acceptance of the hydrodynamic theory. Judging from reviews, Köhler, whose work (1897) has not been accessible to the present author, criticizes this theory in detail. E. Bircher (1915) carried out numerous shooting experiments, which he, largely speaking, considered himself able to explain according to the hydrodynamic theory. This, however, would not be possible in questions of the tracks through clay blocks with their narrow entrance and exit holes, and wide, more or less irregular inner parts. 'Obschon es sich um feuchten Lehm handelte, so sind doch keine hydrodynamischen Kräfte zur Wirkung gekommen. Es muss sich hier um dasselbe Phänomen handeln wie beim Beschiessen von Wasser oder mit Wasser gefüllter Büchsen, wo bei der grössten Geschwindigkeit des Geschosses der hydrodynamische Druck gar nicht mehr zur Geltung kommen konnte. Nur braucht hier dem relativ geringen Feuchtigkeitsgehalt die Geschwindigkeit auch eine relativ geringere zu sein. Die Lehmteile verlieren beim Auftreffen des Geschosses ihre geringe Kompressibilität vollständig, sie können nicht oder nur wenig ausweichen, sie werden einfach zusammengepresst und werden wie ein fester Gegenstand durch-

schlagen'. (Bircher did not, thus, take into account that a track of this kind is just what is to be expected as a result of hydrodynamic action in clay, which even at that time could be seen from the ballistic literature. The present author would not have taken up Bircher's interpretation so fully if it had not had a decisive influence on the subsequent medical literature). Meixner (1927) considered that various extensive shot fractures could be explained as directly traumatic on account of their similarity to fractures from blunt violence. (All experience, both patho-anatomical and experimental, argues against this view).

Many theories have been advanced to explain the Krönlein shots. Tilmann (1900) considered that an abnormal shot situation must have been in question, e. g. 'Wasserschuss', or a shot with the muzzle of the gun immediately against the skin, so that the powder gases also streamed into the canal. (Later experiences contradict these views). Supported by experiments with models, Henne (1900) thought that it was the explosive effect in the cerebrospinal fluid at the base of the skull that threw out the brain as a whole. Reger (1901) added to this that the large blood spaces at the base of the skull might also help to create the fluid-filled space necessary for an explosion of this kind. Hildebrandt (1904) made shooting experiments with blocks of clay, which showed a marked 'Afterwirkung' (see above), i. e. a sucking in of air into the wide shot canal, and used these experiments to support the view that it was this inrushing air that threw the brain out of the skull. (Although the observation that air rushes in is indisputable, Hildebrandt's mechanism is out of the question, as the inner air pressure can *never* overcome the outer one.) In a lecture at the German Surgical Congress 1908, Franz (1908) declared that the Krönlein shot was nothing more than the highest degree of explosive effect, set up under two conditions, both of them rare: 1) Explosive effect so strong that the soft parts also burst. 2) Shot canal running between or under the hemispheres of the cerebrum. In the subsequent discussion, Krönlein, Kocher, and Tilmann spoke. In a later work (1910) Franz gave an account of numerous experiments which confirmed his view. *Inter alia* he succeeded in 3 cases out of 14 in getting a Krönlein effect on conserved human heads.

Mertens (1917) thought that the rotation of the projectile was a necessary condition for the Krönlein shot. (His deductions are obscure, however, and his few experiments not convincing.' Regarding conceivable effects of the rotation of projectiles we can, with Payr (in Schjernings Handbuch, 1922) maintain that the collected kinetic energy of the projectile is conditioned by the rotation only to $^1/_2$ % at the muzzle, and only to $3\,^1/_2$ % after 2000 metres, and that during its passage through a skull, a projectile only completes $^1/_2$—1 rotation.)

Brain injuries set up can also, according to Tilmann (1898), be explained by the hydrodynamic effect. He showed that shots at an uncovered brain splintered it in all directions, but that even a linen covering reduced the splintering and he only got raggedness round the shot canal. Needless to say, a surrounding skull gave an even more effective protection against explosion, but the injuries in the brain still find their explanation in 'eine gewisse Dehnung des Gehirns, oder besser gesagt eine gewisse Aufblähung, in einer ungefähr senkrecht zum Schusskanal stehende Richtung ... Diese Zerrung ergreift das ganze Gehirn, verläuft radiär vom Schusskanal nach der Peripherie, ist in der Nähe des Schusskanals am stärksten und nimmt nach der Peripheri zu ab.' Mertens (1917) thought that the brain injuries were due to the rotation of the projectile through 'Widerstandsströmungen'. (The impossibility of this idea has previously been shown). Genewein (1918) repudiated the hydrodynamic theory for the brain injuries. If this theory is true, the brain injuries ought, in his opinion, to be much greater (cf. von Bergmann and others). Instead, he took up Bircher's opinion, reviewed above, and asserted that the shot had a 'Seitenwirkung', whose nature is not apparent in detail, but which would explain both the cerebral injury and the explosive effect on the skull. The cerebral injury would be due to compression of the tissue, and this would be weakened because the tissue resists 'die Seitenwirkung'. (Genewein's 'Seitenwirkung' is thoroughly mysterious, and seeks its main support in Bircher's previously criticized and erroneous interpretation of a number of his shooting experiments. This does not prevent Genewein's view from being found in hand books and text books as an explanation of injuries to the brain).

5. Summary.

Summing up, we can therefore state the following with regard to the earlier treatment of problems presented here:

1. Regarding facts. There are no extensive statistics over skull and brain injuries with complete data for injuries to the outer soft parts (i. e. where violence is applied), to the skull, to the cerebral membranes, and to the brain. Nor can we find any mathematico-statistical treatment of the connexion between the different injuries.

2. Regarding the theoretical explanations.

A. Regarding the fractures to the skull, there is on the whole unanimity, and the physical explanations advanced appear correct.

B. Regarding the cerebral injuries and the physical background of concussion of the brain there is a large number of contradictory theories which (as was shown above) are in many cases physically untenable.

3. There is no uniform theory for all injuries. The literature deals as a rule either with skull fractures from blunt violence or cerebral injuries from blunt violence or gunshot injuries, or concussion, or only partial problems of these. Thus there is no general application of impact physics, and even in the physical literature little regard has been paid to this problem. In questions of the injuries to the skull, it can be established that the fracture mechanisms are derived from experiments with and theories for compression. Concerning the cerebral injuries and concussion the theories advanced reckon as a rule quite statically with the same condition in the whole of the cavum cranii for each moment of time.

4. Over and above all the facts that have in this way been subjected to various attempts at explanation, the literature also contains a number of hitherto altogether unexplained facts, amongst which may be mentioned:

A. Different forms of fracture inflicted by different instruments.
B. Different cerebral injuries in different forms of fracture.
C. Different cerebral injuries in different ages.

The aim of the investigation presented here is to try to some extent to fill up these gaps in our knowledge.

Chapter III.

The Author's Investigations.

1. The material.

The author has collected two different investigation materials, namely, one of records from the medico-legal institution at the University of Lund, and an anatomical one of specimens from medico-legal and pathological autopsies during the period this investigation was proceeding.

The first material comprises all the medico-legal autopsies during the years 1919—1941, where visible injuries to the skull, cerebral membranes, or brain had been found (with the exception of injuries in infants, mainly the group Infanticide; this group will be given special treatment). The records of these obductions are kept with the exactitude and wealth of detail that set rules demand. This wealth of detail has enabled the author to reproduce schematically the appearance of the injuries both in scalp, bones, and membranes, and in the brain itself. It has further been possible to collocate, on fairly uniform principles, the appearacne of the injuries with the course of events at their infliction. Regard has also been paid to the incidence of other bodily injuries and to the main cause or causes of death.

It is of importance to point out that the activity of the institution was carried on under the same Chief, Professor Sjövall, during the investigated 23 years, and that most of the autopsies were made by him in person (Tab. 1.). An inspection of the material plainly shows, however, that the detailed analysis of the course of events has with the years become more and more exact: this is particularly true of the preponderating part of the material, the highway accidents.

This part has been used for statistical treatment. Concerning

the selection, the following fundamental viewpoints are of importance:

Among all the persons sustaining violence to the skull there is a self-evident selection by virtue of the fact that the material consists of persons that died. The dead are subsequently selected according to forensic viewpoints, and concerning these it can *a priori* be said that they are not correlated to the purely physical genesis of an injury to brain or skull (as the site and force of the violence). Table 1 shows the forensic classification of the cases.

TABLE 1. *The material according to:*

Year the autopsy was performed	Forensic viewpoints					Autopsy performed by			Total
	Homicide	Suicide	Accidents		Unknown	The Chief	The author	Others	
			Highway accidents	Other accidents					
1919–1926	3	4	2	7	2	17		1	18
1927—1931	4		36	5	2	34		13	47
1932—1936	4		54	11	3	70		2	72
1937—1941	10	1	53	17	1	65	9	8	82
Total	21	5	145	40	8	186	9	24	219

While homicide is fairly constant during the whole period of time, and suicide is very rarely submitted to medico-legal investigation (the cases here were five of shots through the head under somewhat obscure circumstances), we find that the highway accidents have increased very greatly with the years. Other accidents fall in detail into the following groups (Tab. 2.):

TABLE 2. *Course of events in the cases of:*

Homicide		Suicide		Other accidents	
Gunshot	2	Gunshot injuries		High fall	15
Gash	5	at close discharge		Low fall	16
Blow	13	in the right temple	5	Gunshot	3
Gash and blow	1	Total	5	Railway acc.	3
Total	21			Blow	3
				Total	40

The material falls into the following groups in respect of age and sex, and according to 'forensic viewpoints' (Tab. 3.):

TABLE 3. *The material according to age and sex.*
(Big figures = all cases; small figures = females.)

Forensic viewpoint	Age										Total
	0—9	10—19	20—29	30—39	40—49	50—59	60—69	70—79	80—89	?	
Homicide	1^{1}	4^{2}	3^{2}	5^{2}	3^{1}	2^{1}	1	1	1		21^{9}
Suicide			1	1	1	1				1	5
Highway acc.	11^{5}	18^{7}	39^{11}	24^{3}	17^{4}	14^{2}	12^{1}	9^{3}		1	145^{36}
Other acc.		6^{1}	5	2^{1}	11	9	4	2	1^{1}		40^{3}
?	1		3	3	1						8
Total	13^{6}	28^{10}	51^{13}	35^{6}	33^{5}	26^{3}	17^{1}	12^{3}	2^{1}	2	219^{48}

It is striking that the distribution of sex is so different in the different groups. Among murdered, the number of men and women is about the same, among the suicides there are no women, and there are very few of them in the accidents other than highway accidents. In the highway accidents there are 109 men to 36 women.

More important from the point of view of selection is the fact that the material comprises 1) cases where the brain or skull injury was so severe that it alone proved fatal, 2) cases where the injury was slighter, and where death was due to other injuries or affections, alone or in combination with the brain injury. This means that if the whole of the material presented here is tabulated according to the extent of the violence or of the injury (and these should *a priori* be considered to be positively correlated), *all* cases of very severe (always fatal) injuries will be included, together with a decreasing number of less severe injuries (only fatal to a certain per cent), and a random selection of slight (not fatal) skull and brain injuries — when, that is to say, these last are combined with fatal injuries to other parts of the body. There is therefore a risk that the slight injuries to skull and brain will be under-represented with consequent risk of false connexion. In so far as such risk can be thought to have been incurred, it will be pointed out in the following pages.

In order if possible to assess this risk the whole material has

been classified according to cause of death as apparent in the medico-legal report. In so doing it has been found suitable to divide up the material into the following groups:

Designation	*Definition*
Brain alone	Injury to brain alone fatal.
Aspiration	Death from the aspiration, due to unconsciousness, of blood, vomited contents of the stomach, or something else; alone or in combination with the brain injury.
Pneumonia	Death from pneumonia due to a lengthy lowering of consciousness; alone or in connexion with the brain injury.
Extradural haemorrhage	Death from extradural haemorrhage; alone or in combination with the brain injury.
Bodily injury	Death from injuries to the face, trunk, or limbs; alone or in combination with the brain injury.
Meningitis	Death from meningitis due to the skull injury; alone or in combination with the brain injury.
Complication or cause of death not clear	Cause of death not satisfactorily established by the autopsy, or due to different, not previously mentioned complications in the injuries sustained (e. g. fat- and lung-emboli, freezing).

As well as this, data have been taken from the course of events as to the time elapsing from the act of violence to death ('the time till death'). This has an effect on the anatomical appearance of the injuries, e. g. by the continued bleeding or incipient reactive

TABLE 4. *The material according to 'Time till death'.*

Forensic viewpoint	0 *	Hours		Days									?	Total
		1–6	7–12	1	2	3	4	5	6–10	11–15	16–20	> 20 **		
Homicide	9	1	1	1	1					1			7	21
Suicide		2	2										1	5
Highway acc.	56	30	11	22	2	11	4	2	4	1	1	1^{26}		145
Other acc.	11	4	7	5	3	2	2	1	4				1	40
?	1	2		1				1	1		1	1^{50}		8
Total	77	39	21	29	6	13	6	4	9	2	2	2	9	219

* 'Immediate death', exact reports seldom available; as a rule within half an hour.

** Small figures in this column give the time in days.

processes round the injuries (cf. Wolff 1932 and 1936, and Esser 1933). Further, the different manners of death may well differ as regards this. Tables 4 and 5 show the division of the material in these respects in combination with forensic viewpoints.

TABLE 5. *The material according to 'Causes of death'.*

Forensic viewpoint	Brain alone	Aspiration	Pneumonia	Extradur. haemorr.	Bodily injury	Meningitis	Compl. and ?	Total
Homicide	11		1	1	7		1	21
Suicide	4	1						5
Highway acc.	82	12	15	6	22	4	4	145
Other acc.	18	3	4	6	6	2	1	40
?	4		2	1		1		8
Total	119	16	22	14	35	7	6	219

There are no noteworthy differences to be found other than as regards the time till death in the different groups of 'Causes of death' (Tab. 6.). While there is a great accumulation of deaths from brain or bodily injury in immediate association with the act of violence, and scattered cases over a long period afterwards, death from aspiration occurs only in close temporal connexion with the violence. Pneumonia, extradural haemorrhage, and meningitis require varying times to develop, and as a result of this these cases of death fall due later. Cases with extradural

TABLE 6 a. *'Time till death' in the different groups of 'Causes of death'.*

Causes of death	Time till death													Total
	0	Hours		Days									?	
		1–6	7–12	1	2	3	4	5	6–10	11–15	16–20	> 20		
Brain alone	50	22	12	18	3	5	2		1		1		5	119
Aspiration	9	6	1											16
Pneumonia				5	1	7	1	2	4	1		1^{50}		22
Extradur. haemorr.		2	4	4	1		2		1					14
Bodily injury	18	8	3	2							1		3	35
Meningitis						1	1	2	2			1^{26}		7
Compl. and ?		1	1		1				1	1			1	6
Total	77	39	21	29	6	13	6	4	9	2	2	2	9	219

TABLE 6 b. *Means with standard errors* ($M \pm \varepsilon_{(M)}$) *and standard deviations* (σ).

Causes of death	Time till death, days		
	Number	$M \pm \varepsilon_{(M)}$	σ
Brain alone	114	0.69±0.18	1.97
Aspiration	16	0.056±0.020	0.081
Pneumonia *	22	6.23±2.17	10.19
Extradur. hæmorr.	14	1.67±(0.60)	(2.24)
Bodily injury	32	0.12±0.044	0.25
Meningitis **	7	8.43±(2.81)	(7.45)
Total ***	205	1.48±0.31	4.45

* excl. 'time till death' 50 days 4.14±0.65 days.
** » » » » 26 » 5.50±0.78 »
*** » » » » 50, 26 » 1.12±0.16 »

bleeding show an average time till death of 1.67 ± 0.60 days, those with pneumonia a time of 4.14 ± 0.65 days and with meningitis a time of 5.50 ± 0.78 days. The motley group, 'Complication or cause of death not clear', are of no interest in this connexion: here we have both long and short periods extensively scattered.

The anatomical material consists of about 50 specimens from different autopsies, made by the staff in charge at the pathological institution in Lund during the period 1937—1943. This is an entirely arbitrary selection of cases; all they have in common are injuries to the brain. This arbitrariness and this systematic selection are, however, alike of no consequence, since the cases are only used for illustration, and are not, as a group, subjected to statistical treatment.

The investigated brains have as a rule been cut with a macrotome into 8 mm slices and then photographed or reconstructed life-size with the glass reconstruction method. Microscopic investigation has been made in a number of typical cases, some of these in complete series, which made it possible to reconstruct on an enlarged scale.

The stereoscopic pictures are taken with the help of the so-called stereoscopic model effect. This reduces all dimensions equally, which thus makes possible a better use of the stereoscopic powers of distinction. The author has dealt with the appartenant stereometry in a previous work (1940).

2. Anatomical investigations and definitions.

a. The nature of the violence.

Violence can be characterized in three different respects as regards its suitable classification in the problems presented here: 1) As regards the shape of the instrument, 2) according to the speed with which the instrument encounters the head, and 3) according to whether the head is, when encountered, in motion or free to move, or supported. As regards the shape of the instrument we can differentiate between blunt and edged, and the blunt instruments can in their turn be divided into plane and 'shaped', i. e. more or less curved surfaces, edges, and corners. Speed is denoted preliminarily only as slow, fast, or very fast; it will appear from the latter division what speeds are concerned in practice.

If these categories of division are collocated (as in the following survey of all conceivable cases), we see at once that certain cases are of no interest, either because they do not occur in practice or because the combination of properties rules out deep injuries (= injuries to skull, membranes and/or brain).

Thus violence which approaches a free head slowly cannot possibly cause injuries to the skull, still less to the brain. This gives a first indication of the importance that the inertia of bodies has in the problems here. It is precisely the great speed in blows and collisions, and the resulting great accelerations and retardations respectively, that make it possible for a free head to be injured — and severely injured — in impacts. In acceleration (and retardation, these being analogous, physically) reactive forces are formed directly proportionate to the acceleration. It is these forces denoting the body's resistance to changes of velocity that we call inertia (forces).

A supported head does not change its speed when it is hit by an object, and the principle is the same whether this object comes slowly or quickly.

When, however, the violence has very great velocity behind it (and as the survey shows this applies to projectile velocity), the distinction between free and supported head ceases to have practical significance. The velocities here are so great that the

inertia forces become the completely dominating ones. Here we get on to phenomena that cannot be treated according to the physical rules for rigid bodies; we have instead to take into account the transmission of violence according to the rules of elasticity. The problem will be dealt with later. We will only say here that an injury will already have had time to develop in the head before any supporting surface that may be there has felt the violence transmitted through the skull.

Nature of violence	Combination without practical significance; cause	Combination with practical significance; example
Plane violence		
To free head		
Slow:	No deep injuries	
Fast:		Free fall. Collision
Very fast:	Unknown	
To supported head		
Slow:		Run over. Crushing
Fast:	Almost unknown	
Very fast:	Unknown	
Shaped violence		
To free head		
Slow:	No deep injuries	
Fast:		Collision. Blow with weapon
Very fast:		Shot
To supported head		
Slow:		Crushing
Fast:		Blow to supported head
Very fast:		Shot
Edged violence		
To free head		
Slow:	No deep injuries	
Fast:		Sharp gash
Very fast:	Unknown	
To supported head		
Slow:	No deep injuries	
Fast:		Sharp gash
Very fast:	Unknown	

After excluding the combinations that have thus proved without practical significance, the following groups remain:

1. Fast, blunt violence to free head.
   a. plane violence
   b. shaped violence.
2. Slow or fast, blunt violence to supported head.
   a. plane violence
   b. shaped violence.
3. Gunshots.
4. Edged violence.

(N. B. When the term 'Blunt violence' is used hereafter, it applies only to Groups 1 and 2, not to the 'Gunshots' group.)

b. **The injuries.**

In the following subsections the injuries will be systematically described according to the classification of the violence given in the previous section. The injuries to the scalp, the skull, the membranes, and the brain itself will thus be described in turn.

a. The scalp.

The scalp is directly exposed to violence; on account of its plasticity, injuries to it are confined to the site of violence and therefore give a good idea of the nature of this violence. The following description of superficial injuries can be considered motivated as the author has used them together with the investigation of the course of events to group his cases according to the nature of the violence.

1. Of course, one application of blunt violence to the free head only gives one injury to the scalp. We get a first principle for dividing the different types of such injuries by the presence and absence respectively of signs that the violence was applied tangentially, so-called signs of direction of motion.

In plane violence the superficial injuries not showing such signs of direction of motion are of different kinds. There is either a superficial injury in the skin with bruising of the epidermis and drying-up of underlying tissue — hereafter called »stamping»

(Fig. 7 a and 10 a.) — or else an irregular contusion wound in the skin, with ragged, undermined borders and numerous tissue bridges (Fig. 7 a.), or merely a rounded haemorrhage under an uninjured skin surface. In all cases the size of the injury is the same, about 2—3 cm in diameter, whether it be the subcutaneous haemorrhage, the undermining, or the described stamping. This strikingly constant size of the superficial injury is due, of course, to the form not of the instrument but of the skull. The compression of the skin between a plane surface and the skull is taken in the speeds in questions just so far as to stamp out or contuse an area about the size of a shilling. The appearance of stamping or contusion wound seems to provide certain possibilities of assessing the detailed structure of the surface inflicting injury. Thus, largely speaking, there is bleeding under uninjured skin in falls against a hard floor or an asphalt road, stamping in the skin in falls against or blows from some rather more uneven surface, and, finally, the ragged contusions in falls on to a gravel road.

The superficial injuries resulting from shaped violence, and not showing signs of direction of motion, are themselves 'shaped', i. e. they reproduce the more or less pronounced shape of the striking surface, whether in wounds or stampings (Fig. 10 a.), or possibly subcutaneous bleedings. The extent of the injury then depends, needless to say, on the size of the striking surface.

The superficial injuries showing signs of direction of motion are also of different types, when they have been caused by plane or by shaped violence respectively. In plane violence we get the typical grazing of the skin with its parallel scraping of the epidermis and its similarly adhering epidermal flaking. In shaped violence we get deeply undermining wounds, running obliquely through the scalp, whence they may continue as more or less extensive scalping injuries.

2. Typical violence to a supported head ought to give injuries in the scalp at diametrically opposite points of the skull. Each of the injuries look like those resulting from violence to the free head, however, and consequently depend on the properties of the instrument inflicting them (plane or shaped, acting at right angles or tangentially). Needless to say, there is nothing to stop two opposite injuries from being of different types.

The author has kept fairly strictly to this qualification for consignment to the group 'Supported head'; only when the evidence has been absolutely clear has a case with only one superficial injury been relegated to this group. Conversely, cases with diametrically opposite injuries of about the same size have been consigned to this group only if there was probable evidence; otherwise they were added to a group of uncertain cases, 'Free? supported head'.

Of course, there are situations when the head rests on a soft surface, and where no superficial injury whatsoever is inflicted on the supported side of the head. There are two such cases in the material: One of murder with blows of a hammer on the head of a sleeping person, the other of someone run over by a lorry out on a clayey field.

3. The injuries to the scalp resulting from gunshots are far too well known to be touched on in more detailed here. The material includes shots from a shotgun, from firearms (saloon rifle, revolver, and pistol are represented), and from an exploding tank-mine. A well demarcated group is constituted by the cases of suicide with near discharge effect in the entrance wound (the right temple).

4. Stabs and cuts through the integument are characterized as always by their sharp edges and smooth wound surfaces which run straight or obliquely through the skin. Gashes, too, have these properties in the main (Fig. 22 a.), even if there may be a certain element of contusion in the immediate vicinity of the wound.

In dividing up the whole of the material we have gone on the course of events as testified to in the investigation, and on the properties of these injuries to the scalp (Tab. 7.). This division met with a difficulty, namely, that in many cases there are two or more surface injuries over the free parts of the skull. In such cases it is not immediately clear which of these injuries belong to violence inflicting deep injuries (i. e. injury to skull, membranes and/or brain). In questions of firearm injuries or injuries from edged violence it is, however, easy to demarcate the capacity of this or that violence to inflict deep injuries: Among the eight firearm injuries, there is no case with more than one shot canal; nor do the shotgun and splinter injuries provide any difficulties

TABLE 7. *The material according to type of violence.*

Group	Definitions	Homicide	Suicide	Highw. acc.	Other acc.	?	Total
0	Cases with diseases of brain or without known violence				1	4	5
1 and 2	Blunt violence A. One surface injury						
	Violence to free head	1		78	28		107
	» » supported head			1			1
	» » free? supported head				1		1
	B. Two or more surface injuries						
	All applications of violence to free head	6		54	7	2	69
	All applications of violence to supported head	1		6			7
	Applications of violence of both types (1 case) and uncertain cases	5		6		2	13
3	Gunshots	2	5		3		10
4	Edged violence	5					5
In addition	One case with 2 edged and 1 blunt violence	1					1
	Total	21	5	145	40	8	219

in this respect. And injuries from edged violence are always directly connected with the surface injury. In questions of injuries from blunt violence, on the other hand, those cases are primarily ruled out that only show *one* surface injury, for in these cases we can be certain that this spot is where the violence causing deep injuries is applied, and that all deep injuries found are due to just this application. (The material contains no case of traumatic effect to skull, membranes, and brain that does not have at the same time injury to the scalp round the skull). From these those cases are then removed where it is doubtful whether the violence encountered a free head (two cases). A sorting of the remaining cases *(one* application of blunt violence to the free head) according to the appearance of the superficial injuries (Tab. 8.) shows, as expected, a fundamental difference between cases exposed to plane violence, and those exposed to shaped

TABLE 8. *Group 'Blunt violence to free head. One surface injury'. According to the surface injury.*

Violence	Type of injury	Violence			Total
		plane	shaped	?	
Non-tangential	Bleeding under uninjured skin	28	2	1	31
	Stamping	24	2		26
	Contusion wound	20	1	1	22
	Shaped wound		12		12
Tangential	Scraping	1 *			1
	Scalping	1 **	4		5
?	Incompletely described and surgically treated respectively	5	2	3	10
	Total	79	23	5	107

* Case 167 (p. 73).
** Case 198 (p. 74).

violence. Shaped wounds never occur within the former group; in the latter, this type of injury predominates. Surface injuries with signs of direction of motion are rare in both groups. The four cases of shaped wounds with signs of direction of motion (scalping injuries) all have this in common, that they show 'shaped fractures' in the bottom of the wound. In type, therefore, these injuries are quite near to the edged injuries. The two cases of this kind, in the group 'Plane violence', can be considered on good grounds as incompletely registered, so that it is highly likely that plane injuries with signs of direction of motion have no corresponding deep injuries.

This fact is explained by the physical situation in the collision of bodies: The velocity of colliding bodies is, of course, considerably altered during the very short time the impact lasts, and any accelerations and forces will therefore be very great. (The classical impact theory reckons with infinitely short time and infinitely great forces). These very great forces, the impact forces, are directed at right angles to the surface of contact between the colliding bodies, and this holds both for direct and oblique impact. Compared with these, other forces can be completely ignored during the time the impact lasts. In so far as a course of impact is set up in violence to the head — and this is

the prerequisite for the deep injuries — the forces of any importance are thus at right angles to the surface of the body, and the injury in the scalp shows no signs of the direction of motion. It is not until there is pronounced tangential violence that such signs are shown, because then the violence affects the scalp only.

TABLE 9. *Group 'Blunt violence to free head. Two or more surface injuries'. According to surface injuries.*

		Number of injures in each case					Total
		2	3	4	5	>5	
Number of cases		48	13	3	3	2	69
Violence	Type of injury						
Non-tangential	Bleeding under uninjured skin	23	8	5	5	1	42
	Stamping	29	12	3	1		45
	Contusion wound	19	1	4	5	1	30
	Shaped wound	9	5		2		16
Tangential	Scraping	6	8				14
	Scalping with fracture	3	1				4
	Scalping without fracture	6	1		2	5	14
?	?	1	3			6	10
Number of injuries		96	39	12	15	13	175
Number of cases with only one surface injury able to be connected with deep injuries		12	2				14

If we now divide up the cases with two or more applications of blunt violence to the free head according to surface injuries in each particular case, we may, of course, find a number of cases where only one of the surface injuries can be combined with the deep injuries. Table 9 shows that among 69 cases with two or more surface injuries it is possible to gain 14 such cases.

β. The skull.

To describe the injuries to skull, membranes, and brain, it is practical to introduce a spherical co-ordinate system with two poles, meridians between the poles, and parallels. The co-ordinate system is adapted in each particular case to the point or points where violence is applied. Thus in violence to the free head we

get an impact pole and an opposite pole; in violence to a supported head we get two pressure poles.

The author follows Thoma's previously reviewed division of the fractures into local fractures, deformation fractures, and explosion fractures, and the further division of the deformation fractures into meridional fractures and parallel circle fractures (more briefly called parallel fractures).

After this, the author has divided up the meridional fractures according to their length into 'Short fissures' and 'Meridional fissures', and drawn the boundary a third of the distance from impact pole to opposite pole. This gives quite a marked boundary between the small, straight fractures seen near the impact pole, which just because they are so small cannot be placed with certainty on what the report says of them, and the long fissures, running clearly meridionally, which are so characteristic in the skull (Fig. 7 b, 8, 9 a and 10 b.).

There are often two or more meridional fissures at the same time. They are then often of about the same length, and radiate from the impact pole.

Between meridional fissures of this kind, radiating out in different directions, there is often one or more complete or incomplete ring of parallel fractures round the impact pole.

Now, fracture systems with several meridional fissures radiating in all directions, and combined with rings of parallel fractures correspond to the co-ordinate system on a globe and will hereafter be called globus fractures (Fig. 3 and 17.).

The fracture types mentioned hitherto result from plane violence to the skull. The more shaped the violence is, the more will the parallel fractures preponderate over the meridional fractures, and in sufficiently hard and distinctly shaped violence we get injuries to the bone — at any rate to the lamina externa — that exactly fit the instrument.

In such injuries, and when there is one or more complete ring of parallel fractures, it is possible for a fragment of bone to be pressed into the cranial cavity, 'Depression fracture'. This possibility is also present (albeit to a lesser degree) in incomplete rings, since the bone substance is elastic and allows a resilient depression of such incompletely severed bone. Small depression fractures are seen to occur in the squamae temporales after slight,

usually shaped violence, also. The material contains, for example, cases of blows from a fist, where the fracture in the squama exactly fits a knuckle (Fig. 21.), and which proved fatal on account of extradural bleeding.

1. For the statistical treatment the author has chosen the following division of the direct fractures from blunt violence to the free head (Tab. 11.):

1. Cases without direct fracture.
2. Cases with direct fracture.
   - A. Fractures without depression.
     - a. Short fissures.
     - b. Meridional fissures (one, two, or more).
   - B. Fractures with depression.
     - a. With meridional fissures in all directions, 'Globus fractures'.
     - b. With meridional fissures within a limited sector (one, two, or three), 'Sector fractures' (Fig. 2, 18 and 19 a and b.).
     - c. Without meridional fissures, i. e. limited to the segment round the impact pole, 'Segment fractures' (Fig. 20 a and b and 21.).

In the author's material there are a number of cases of ring-shaped fractures round the foramen occipitale magnum. They are all of the type described by Le Count and Hockzema (1934), i. e. resulting either from the joining of two meridional fractures (Fig. 9 a och 17.), or from a cross break between meridional fissures near the foramen magnum (Fig. 8 and 17.).

The material also contains examples of indirect fractures, namely fractures of the orbital roof from blunt violence to the back of the head, and fractures of the dorsum sellae turcicae. *The former* sometimes occur alone (Fig. 14.), sometimes together with other fractures, but independent of them, sometimes as terminal ramifications of meridional fissures (Fig. 8.) — in all cases displaying the characteristic dislocation in towards the cranial cavity; *the latter* do not seem to be systematically registered, and will therefore not be treated statistically.

The fragile orbital roofs have an effect, in addition, on the shape of the fractures from violence to the forehead. In this

region we are therefore more likely to get atypical depression fractures with crushing of the orbital roofs, and this in plane violence also.

Finally it may be mentioned that meridional fissures, and other fracture lines, too, sometimes follow suture lines and force them apart. This happens, however, only when the fracture line, following a course dictated by general rules, coincides or only slightly diverges from the course of the suture line. It is seen that the sutura lamboidea is most often subjected to a distension of this kind, probably because, running obliquely down towards the base of the skull as it does, it coincides with a 'natural' fracture line.

2. When the head is supported, there are as a rule very severe fractures, with many completely loose fragments. The medico-legal reports usually contain no description of efforts to systematize these injuries. When the head is crushed between two plane surfaces, the injury seems to be about as severe on the one side as on the other, while a head supported against a plane and encountering a blow or pressure from a shaped object gets a severe depression fracture on the side of the shaped injury. The explanation of the severe injuries may well be that the violence does not cease on the skull's breaking: it continues to act on the primary fragments (e. g. in persons run over). Only when something else checks the two compressing surfaces just after they have set up the first break can fracture systems be got agreeing with the pure types in violence to a free head. The material contains a few cases that in all probability are of this type; they are cases of running over, when the injured person's head got between the wheels and was crushed between the chassis and the road.

3. The material contains the following gunshot injuries with their different fractures: 1. Two shots from a shotgun fired at close range with severe direct injuries inflicted by the still well-assembled charge. 2. A case where a bullet from a saloon rifle hit the head after having passed through a plank wall. The entrance hole in the bone was irregular in shape, and wider than the calibre, corresponding to the great deformation of the bullet in its passage through the wall. 3. A case of tangential gunshot injury with a saloon rifle at some metres' range, with blowing

out of the oval bone portion between entrance and exit holes. 4. Six cases show gunshot injuries with revolver or pistol of varying calibre (6.35—9 mm). a. In one case, a long range shot with a pistol of 6.35 mm's calibre (murder), there is only a typical entrance wound, but no further bone injuries. b. Five cases of near discharge through the right temple (suicide). Three of these show the explosive effect characteristic of modern firearms, while the other two only show typical entrance and exit holes, together with indirect fractures through the orbital roofs. 5. In the anatomical material there are 6 cases of splinter injuries at a big explosive accident. The splinters consisted of small pieces of iron plate $^1/_2$—1 mm thick, with an area varying from 3×3 mm to about 1×2 cm. Two of the cases show more than one shot injury to the brain. The injuries have a central or tangential course, and the projectiles can be calculated to have encountered the skull with very varying speeds. Two of the shots show explosive effect on large portions of the skull. One of the shots, a glancing one in the left temple, gave in addition to the direct fracture a limited depression fracture of the roof of the left cellulae mastoideae, and also fractured the orbital roof. The others show only typical entrance wounds through the bone, opening inwards. All the entering projectiles remained inside the membranes or the brain (there were no exit holes).

4. Edged violence penetrating the skull sets up fracture injuries exactly fitting the instrument and passing through the vault with smooth surfaces. Fissures *may* occur, specially in gashes, which continue in both directions in the longitudinal direction of the sharp edge more or less far out into the vault or down to the base (Fig. 22 b and c.). Here, of course, we are dealing with a simple wedge effect.

γ. The cerebral membranes.

1. Blunt violence to the free head gives characteristic injuries to the membranes.

The dura mater shows injuries (Tab. 13.) going right or partly through it: both at the impact pole (Fig. 2 and 20 c.) — in which case, in connexion with depression fractures — and along meridional fissures (Fig. 3, 8, 9 a and 10 b.). In this latter case we

get one lengthy fissure in the dura, running approximately parallel to the bone fissure and under the places where this fissure gapes most. To this may be added the typical superficial injuries to the dura that may encounter one of its arteries and which lies behind the picture, well-demarcated clinically and patho-anatomically, of extradural haemorrhage. Sometimes injury is also observed on some one of the sinus durae matris (the picture then being changed, both clinically and anatomically, according to circumstances).

Injuries to the pia and arachnoid are not as easily discernible as previously described injuries; nor are they so completely or so plainly described in the reports. In addition, subdural or subarachnoid bleeding can move easily in the subdural and subarachnoid spaces, so that no certain conclusions can be drawn as to where the source of bleeding is. There are, however, a number of clearly demarcated types of injury to the pia and arachnoid. In such cases, either the dura or the cortex or both are as a rule injured at the same spot on the brain surface as the pia and arachnoid. Such injuries are observed at the impact pole under a depression fracture and along meridional fissures, practically always in combination with fissures through the dura also. Further, the pia and arachnoid are as a rule seen to be ragged and greatly suffused with blood at the opposite pole under uninjured dura, when the brain shows so-called contre-coup. When an injury of this kind is observed on the pia and arachnoid at the opposite pole without simultaneous cerebral injury, we can probably take it that the same causative mechanism was still in force.

It is more difficult to form a judgment when blood is found subdurally or subarachnoidally, or both, without visible laceration of the membranes and without the typical localization previously described. There are cases where such membrane bleeding is localized, and cases where it is diffuse. A special group is constituted by the cases where there is abundant symmetrical subarachnoid bleeding in the basal cisterns and out into the fossae Sylvii. The material is too small to allow of any definite conclusions as to these types of haemorrhages.

2. Violence to the supported head gives, in connexion with the usually very severe bone injuries, extensive lacerations of the

membranes, also. This applies primarily to injuries from being run over, but also to injuries from crushing. In blows to the supported head, and particularly if the underlying support is soft, there is bone injury only at the impact pole and, as a result, the injuries to the membranes must follow from this one.

3. The membranes offer no particular problems in gunshot injuries. The shot canal passes through them as a slit-shaped opening or a more star-shaped laceration, probably due to accompanying bone fragments. Nor do the cases with explosive effect show any very great injury to the dura mater. In the author's own case of pistol-shot injury the canal ran through the orbital roofs and was combined with extensive laceration of the membranes along this canal.

4. In edged violence that goes sufficiently deep clean-cut holes are produced in the membranes also. A noteworthy case is one of a blow from an axe directly from behind, which struck in the median line, penetrated the skin and vault (Fig. 22 c.), and opened the sinus longitudinalis superior, but got no further.

δ. The brain.

The cerebral injuries visible to the naked eye appear pathoanatomically as haemorrhages, possibly around lacerations of the brain substance.

As regards the haemorrhages the author agrees with Wolff's previously reviewed division, namely: 1) Laceration haemorrhages ('Trümmerblutungen'), irregularly spread round lacerations in gray or white substance. 2) Perivascular haemorrhages ('Perivasculäre Raumblutungen') (Fig. 15 a.), spreading out in the perivascular spaces mainly in the cortex of the cerebrum, but sometimes also continuing down round the more scattered vessels in the medulla. 3) Sphere and ring haemorrhages ('Kugel- und Ringblutungen') (Fig. 16 a—c.), the typical medulla form of haemorrhage, whose development has been described previously.

As Chapter II shows, we have described in the literature injuries at the site of violence (the impact pole), injuries at the diametrically opposite point (opposite pole), so-called contre-coup, and haemorrhages in the interior of the brain. To these the author would like to add a type often encountered by him which,

practically speaking, has been ignored in the literature hitherto, namely injury to the surface of the brain along meridional fissures (hereafter called 'Meridional injury').

1. In blunt violence to the free head all four types of injury are observed (Tab. 14 and 15.). Their several localizations give the resulting injury its special type.

Injuries to the brain substance at the impact pole are set up only in depression fractures, never in meridional fissures or when the skull is uninjured. In addition, the dura is practically always injured under the depression fracture. The injuries to the brain are directly caused by penetrating fragments of bone (Fig. 2 and 20 c.), or, when this is possible, by the instrument itself ('Direct brain injuries'). The extent of the injury is similarly conditioned by the penetrating instruments. We can see deep holes after pointed instruments or shaped fissures after sharp bone fragments which were bent into the cranial cavity by the violence applied, but which, being elastic, sprang back to their original position. The brain substance may to a greater or lesser extent be bruised or ragged. Round such laceration there is more or less copious bleeding, in the form either of laceration or of perivascular haemorrhages. The author has not, on the other hand, observed sphere or ring haemorrhages in the impact pole area, even though the injury may have reached the medulla. (His experience is, however, limited in this respect, as the anatomical material involves mainly contre-coup injuries.)

In principle, the meridional fissures in the skull run, as described above, from impact pole to opposite pole. They may be one, two, or more in number. Along one or more of these, lengthy areas of the brain's surface may be lacerated or permeated with haemorrhages. All parts of the skull are equally liable to such injuries when once a fracture starts across it. Owing to the tendency of the meridional fissures to run down over the base of the skull, the cerebellum (Fig. 8 and 27 b.) and under sides of the temporal lobes come to be particularly exposed to such injury. In the vast majority of cases the membranes are also lacerated by lengthy fissures following the direction of the fracture. Smaller injuries of this type are localized round the equator, but the larger ones may reach almost as far as from the impact pole to the vicinity of the opposite pole, where they may continue as a pos-

sible opposite-pole injury. Less serious cases show only perivascular haemorrhages in the cortex (Fig. 8, 9 a and 10 c.); more serious cases give far-reaching lacerations of the cortex and possibly of the medulla also (Fig. 3.). Very serious injuries of this kind are sometimes seen with contused brain substance caught between the edges of the fracture. In two cases, belonging to the statistical material, great defects in the brain are described resulting from the brain substance having been thrown out through lacerations set up simultaneously in the outer soft tissues (in the one case the fracture ran through the roof of the middle ear and the tympanic membrane was torn, in the other there was laceration both of the meninges and of the scalp along the fracture). One of the anatomical specimens shows a peculiar injury of this sort (Fig. 26 a—c.): Along the line of fracture a hernia of cerebellum tissue has protruded through the pia and arachnoid, and, further on, there is a fissure in the pons. There are sphere haemorrhages round this fissure and at the base of the hernia. A special form of such brain injuries is localized at the bottom of the third ventricle and adjacent parts of the brain and is due to the often occurring fractures through the sella turcica and accompanying lacerations of the dura.

Injuries arise at the opposite pole which have been assembled in the literature under the name contre-coup (counter-stroke, Gegenstoss). It can be seen from the name alone how these injuries were generally thought to orginate, namely that the brain at the opposite pole in some way strikes against the inside of the skull. Since the author, as will be seen, has reached another opinion, he will use the term 'Injuries at the opposite pole' instead of contre-coup.

Injuries at the opposite pole may vary very greatly as to size and appearance. In the first place we must keep separate injuries of this kind localized in the cerebrum and cerebellum respectively.

The injuries to the cerebrum can in their turn suitably be divided up into injuries only in the cortex, injuries including both cortex and medulla (to more or less the same extent), and injuries (mainly) in the medulla.

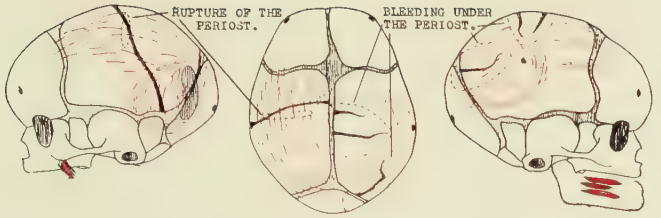
The cortex injuries may have different extent both sideways and downwards. The smallest opposite-pole injuries observed consist of small, limited groups of quite short perivascular haemor-

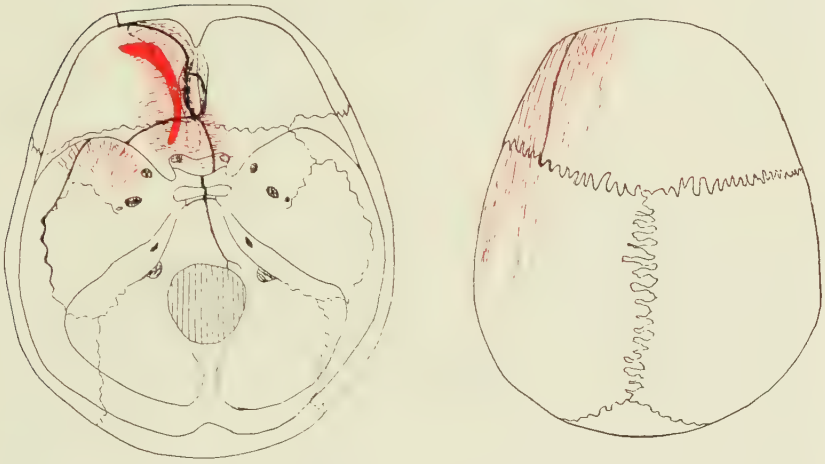
rhages immediately beneath the molecular layer (Fig. 7 b and c.). In rather more serious injuries these are already found penetrating right through the cortex, though usually with the exception of the molecular layer. They are either limited to minor regions on the surface of *one* of the lobes of the cerebrum or spread out over the surface, of one, two, three, or four (Fig. 8, 9 a and b, 10 c.). In the latter case the perivascular haemorrhages may either be in scattered small patches, or else they are evenly disseminated over the whole of the area in question.

The separate bleedings may also vary in type: Sometimes they appear as very narrow streaks through the cortex, more or less sparsely scattered in the injured portions. In other cases they are coarser, and then coalesce with neighbouring ones to form large, sanguineous, softened patches. As has previously been pointed out, such more copious bleedings often continue downwards as long rods into the perivascular spaces in the medulla.

It is noteworthy that the perivascular haemorrhages are sometimes only to be found in those parts of the cortex that face the surface, on top of gyri, whereas the cortex round the sulci is free. In other cases, this latter part of the cortex, too, is full of haemorrhages, as has also been pointed out by Esser (1933 a). They can also be on the median sides of the cerebrum lobes (in widespread injuries to the cortex) without there being any bleedings in the intermediate medulla. In two cases in the anatomical material the author has even seen limited areas of the cortex in the middle of the median sides of the frontal lobes permeated by perivascular haemorrhages, clearly separate from the actual opposite-pole injuries on the anterior and inferior surfaces (Fig. 27 a.).

Opposite-pole injuries of the type including both cortex and medulla (Fig. 11 a—d, 12 a and 16 a.) are in good accordance with the deep contre-coup injuries described by Hewett. These display fissures in the nerve substance forming concentrically round the opposite pole. Outside these formations (i. e. towards the opposite pole) the brain substance is softened and very much suffused with blood, and in very serious injuries large parts of cortex and medulla rendered structureless in this way can be lifted out of a continuous bowl-shaped fissure formation (Fig. 11 a and b.). On the other side of these formations there appear in the medulla





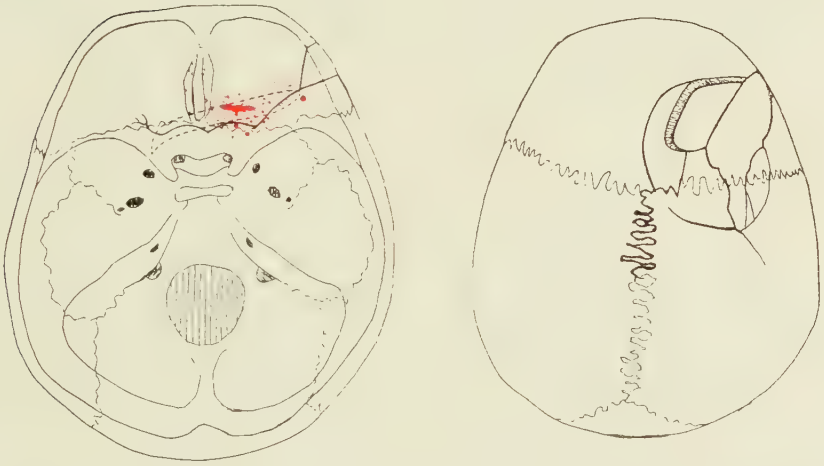


Fig. 1. Meridional system of fissures in new-born child. Impact near tuber pariet. dex. Other surface injuries without deep injuries.

Fig. 2. Sector fracture. Laceration of the dura. Shaped laceration of the brain by depressed fracture edge. Surrounding perivascular haemorrhages.

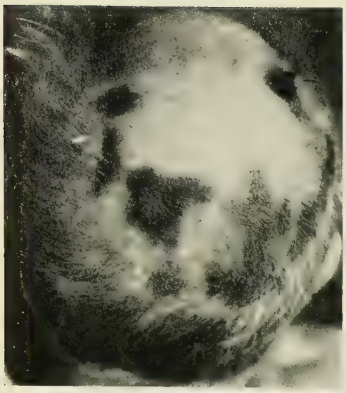
Fig. 3. Small globus fracture. Meridional injury to dura and brain.

Fig. 4. Injury in the interior of the brain. — a. A denser group of haemorrhages near the opposite pole. — b. A sparser and more extended group near the impact pole.

Fig. 5. Injury in the interior of the brain. Multiple small irregular haemorrhages in the putamen, thalamus, corpus callosum, and adjacent parts of the cortex. Symmetrical fissures in the putamen, surrounded by bleedings.

Fig. 6. Large haemorrhage patch in the pons.

7a



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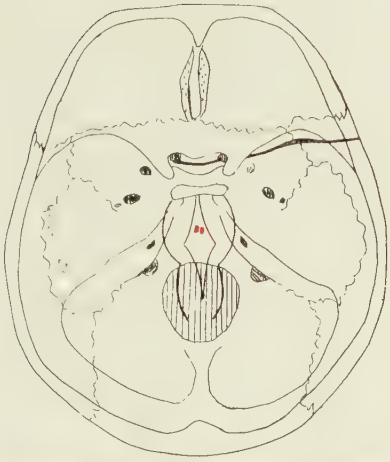
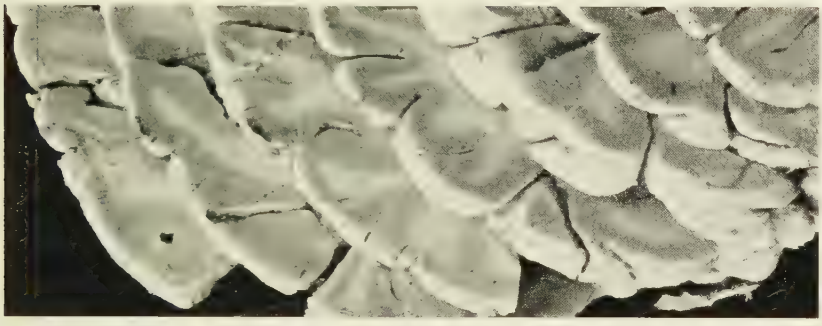


7c



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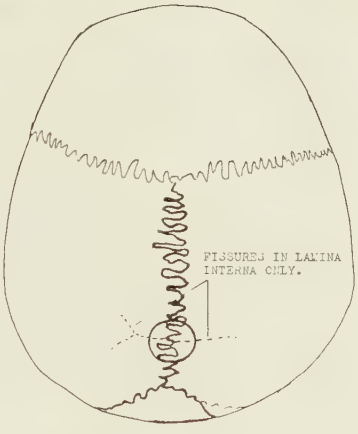
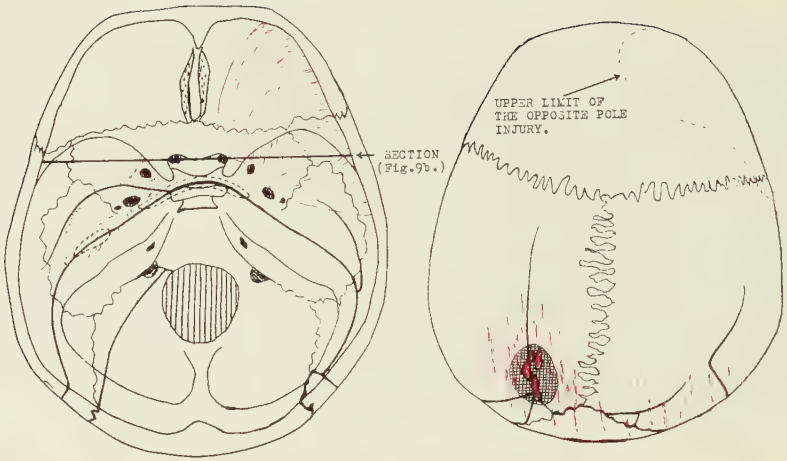


Fig. 7. a. Contusion wound from fall and stampings from rolling. — b. One meridional fissure. Slight opposite-pole injury. Haemorrhages in the bottom of the fourth ventricle. — c. The opposite-pole injury. Slices viewed from behind.

Fig. 8. Wound treated. Meridional fissures. Incomplete ring fracture. Fracture of the orbital roofs. Meridional and opposite-pole injuries.

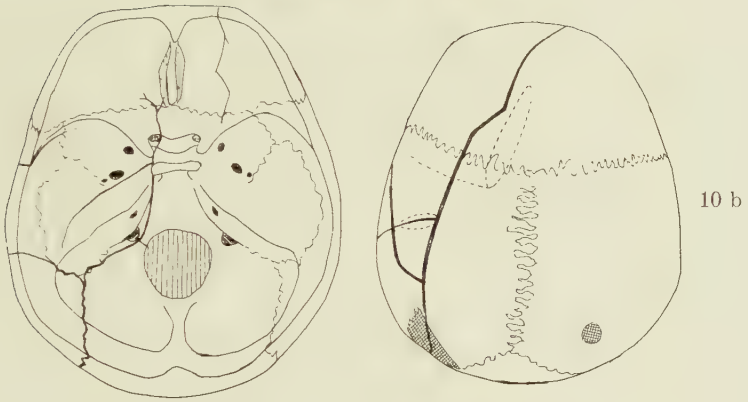
9 a



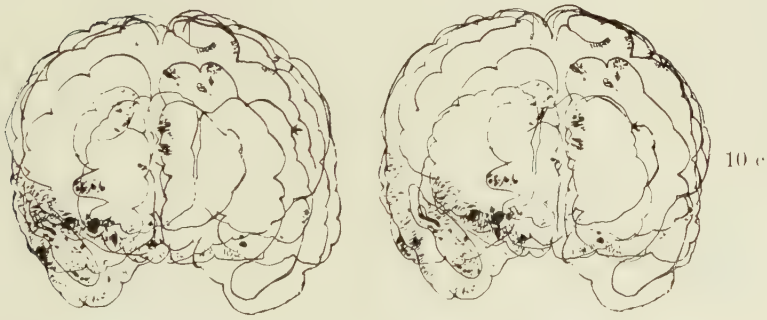
9 b

Fig. 9. a. Contusion wound. Meridional fissures. Large ring fracture from union of two meridional fissures in the sella turcica. Meridional injuries to the dura and brain. Extended cortex injury at the opposite pole. — b. Section, indicated in a. Fine, wide-spread perivascular haemorrhages in the cortex. Slice viewed from behind.

10 a



10 b

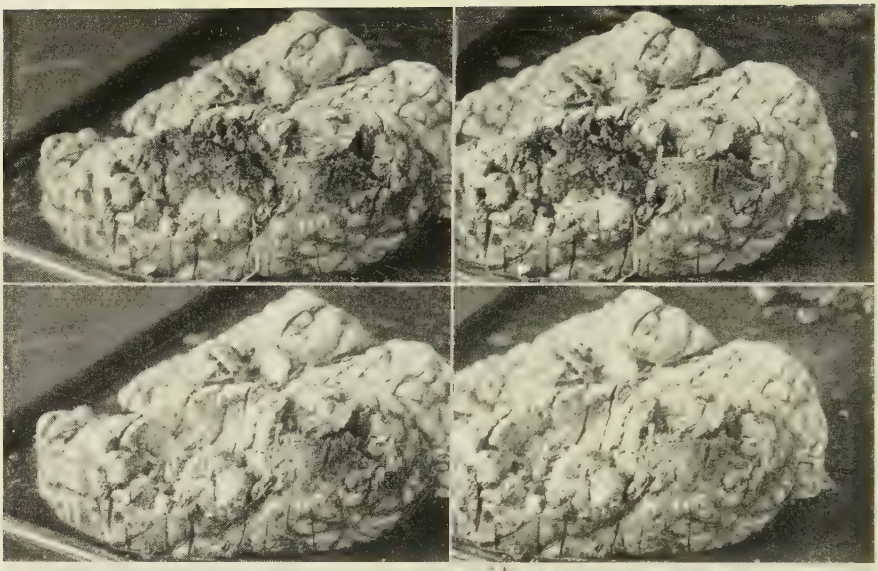


10 c

Fig. 10. a. Shaped stamping. Secondary surface injuries (stampings) without deep injuries. — b. Meridional fissures with one cross break between them. Meridional lacerations of the dura. — c. Brain injuries (perivascular haemorrhages) along the upper meridional fissure and at the opposite pole.

11 a

11 b



11 c

11 d

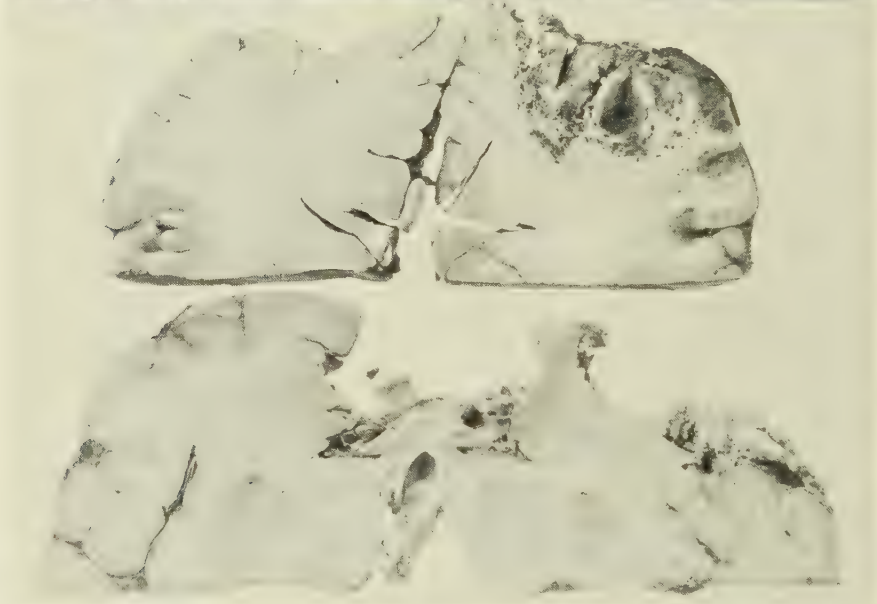
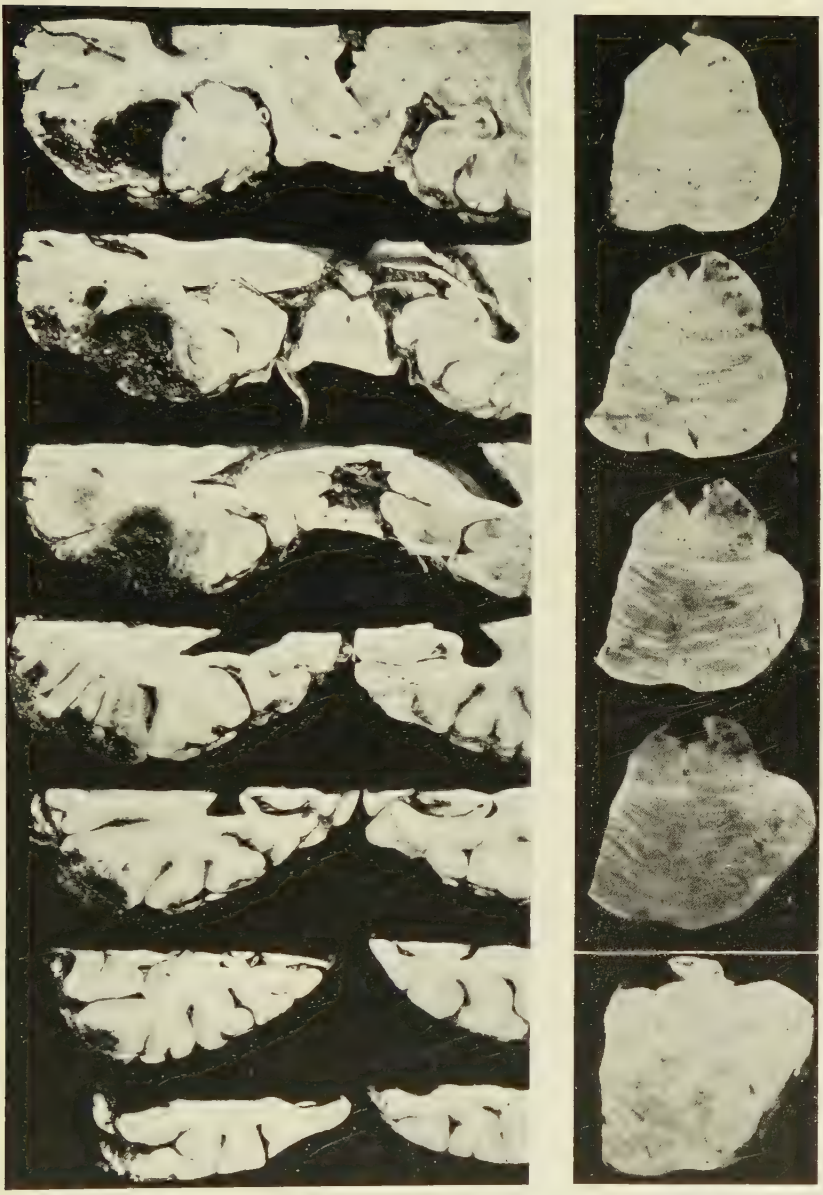


Fig. 11. Brain injury at the opposite pole of the cortex and medulla type. – a. Large parts of the left frontal and temporal lobes structureless and suffused with blood. — b. The structureless parts of the temporal lobe lifted out of the bowl-shaped fissure formation. — c. Slice from the frontal lobe, from behind. — d. Slice from the temporal lobe, from behind.



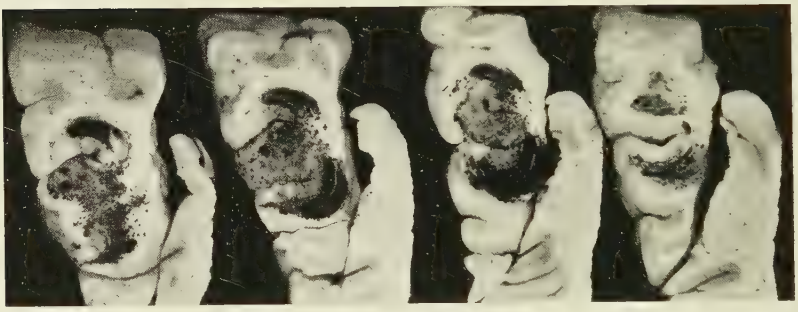
12 a 12 b

Fig. 12. a. Opposite-pole injury of the cortex and medulla type in the left temporal lobe. Small patch of sphere haemorrhages in the medulla at the medial side of the right temporal lobe. Slices viewed from behind. — b. Brain injury in the interior. Patch of sphere haemorrhages to the right of the anterior part of the fourth ventricle. Slices viewed from behind.

1 2 3 4

13 a

13 b



1 2 3 4

14

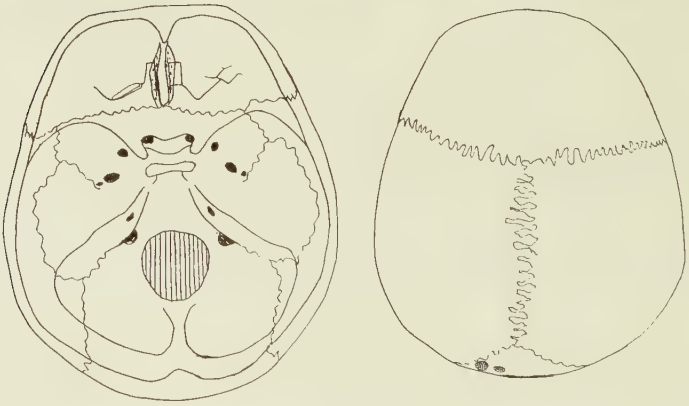
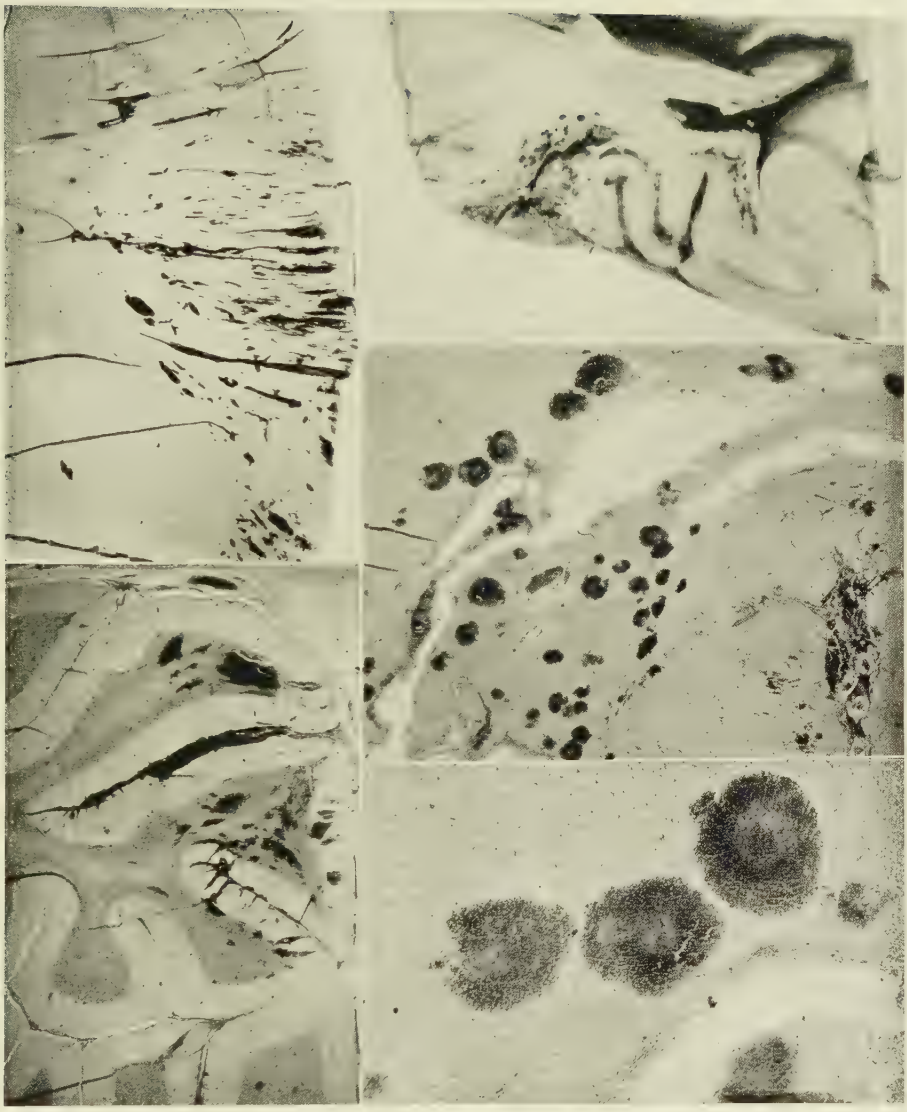


Fig. 13. Opposite-pole injury of the (mainly) medulla type. — a. Right frontal lobe, viewed from outside. — b. Slices, indicated in a, viewed from in front.

Fig. 14. Fracture of the orbital roofs from fall on to the back of the head.

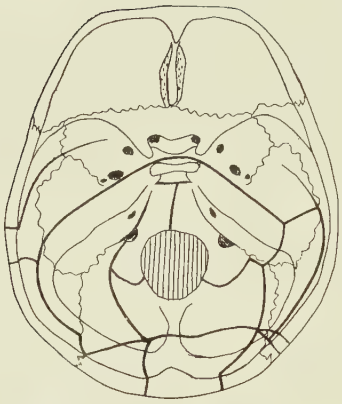


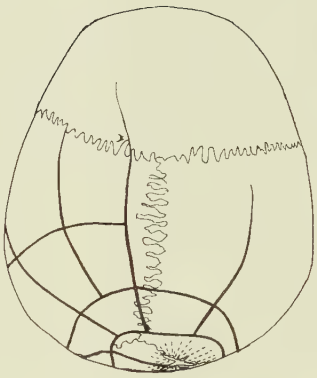
15 16

Fig. 15. a. Opposite-pole injury to the cortex cerebri. Perivascular haemorrhages. — b. Opposite-pole injury to the cortex cerebelli.

Fig. 16. Opposite-pole injury to the brain of the cortex and medulla type. — a. Slice of the right temporal lobe, viewed from in front. Fissure formation into the temporal horn. — b. Microscopical slide from the same slice. Sphere and ring haemorrhages round the fissure. — c. Ring haemorrhages from the same slide.

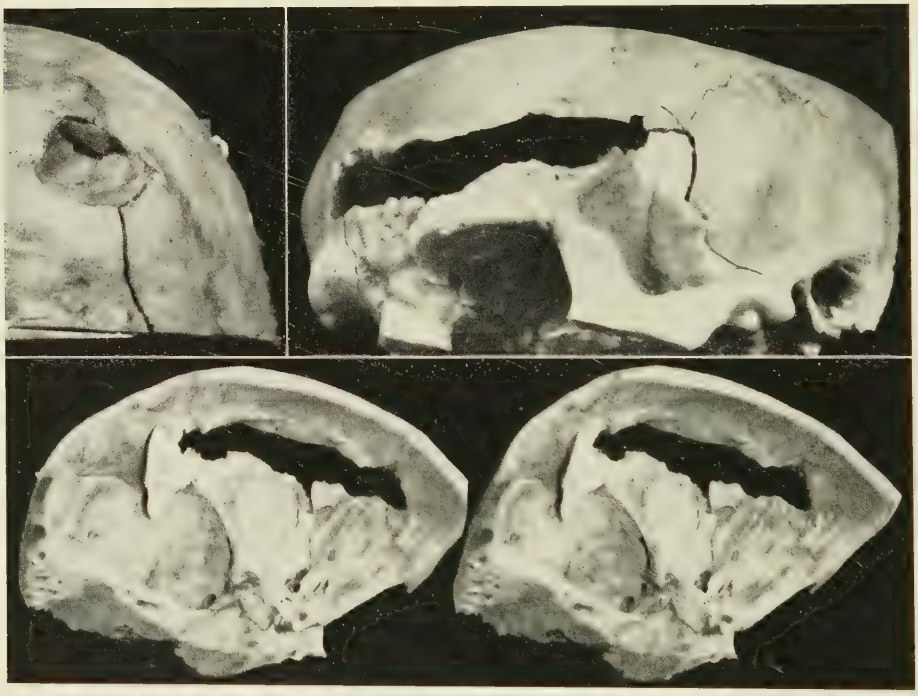
17





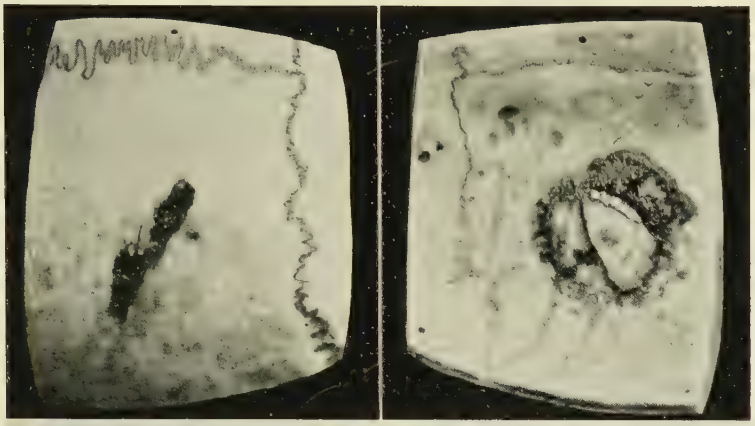
18

19 a



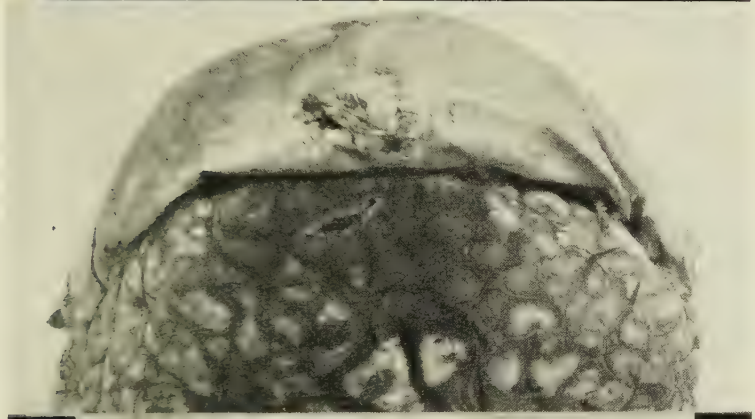
19 b

Fig. 17. Contusion wound. Large globus fracture. Slightly schematized.
Fig. 18. Sector fracture (shaped depression fracture and meridional fissure).
Fig. 19. Sector fracture (shaped depression fracture and three rather short fissures continuing towards the base). — a. From outside. — b. From inside. Hole fracture widening inwards.

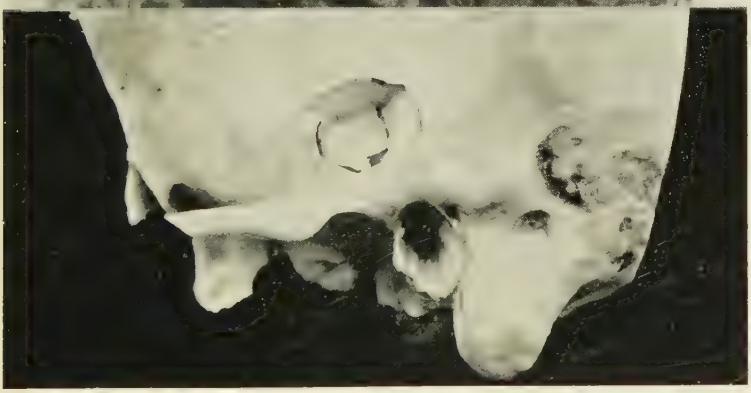


20 a

20 b



20 c



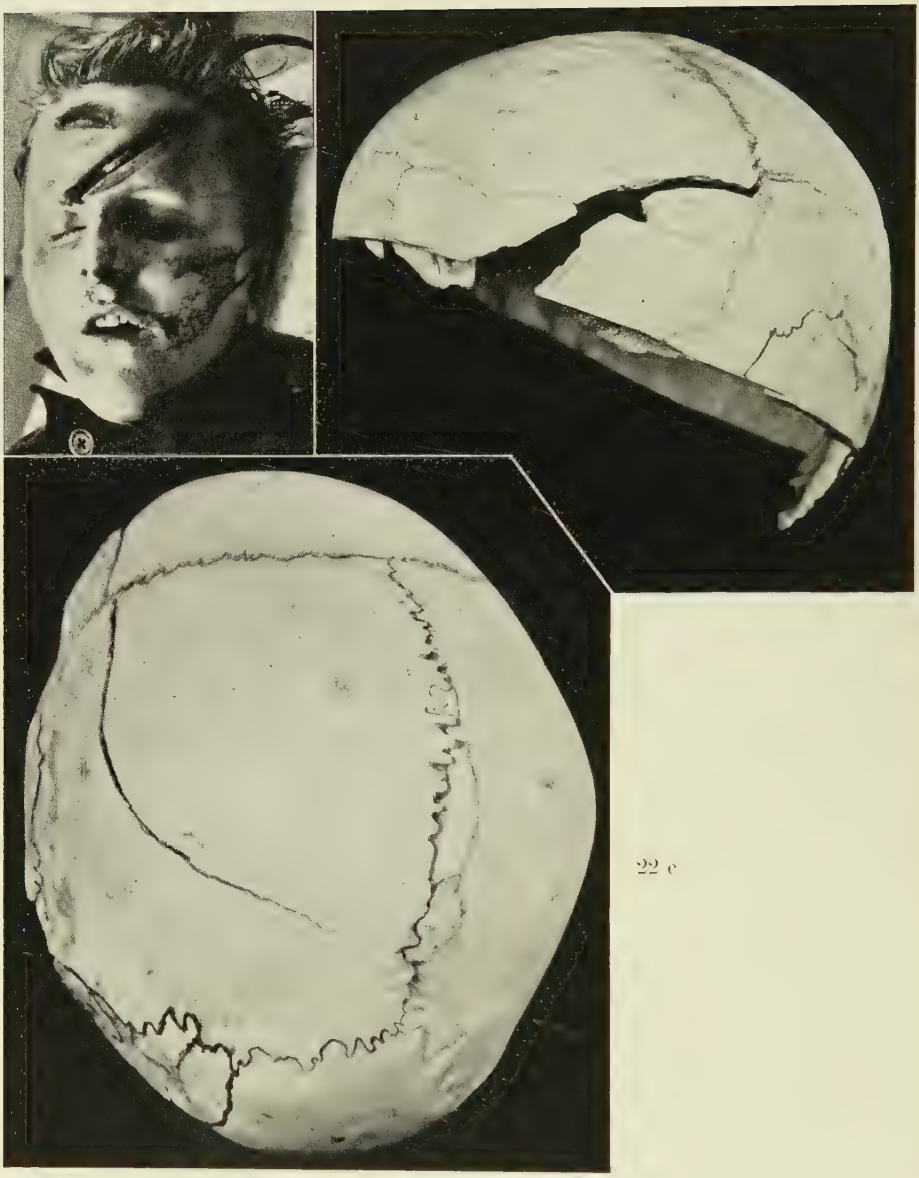
21

Fig. 20. a. Shaped depression of the lamina externa. — b. More extended, round depression of the lamina interna. — c. Clean-cut injury to the dura and brain from the depressed bone fragment.

Fig. 21. Segment fracture (limited depression fracture in the very thin squama temporalis).

22 a

22 b



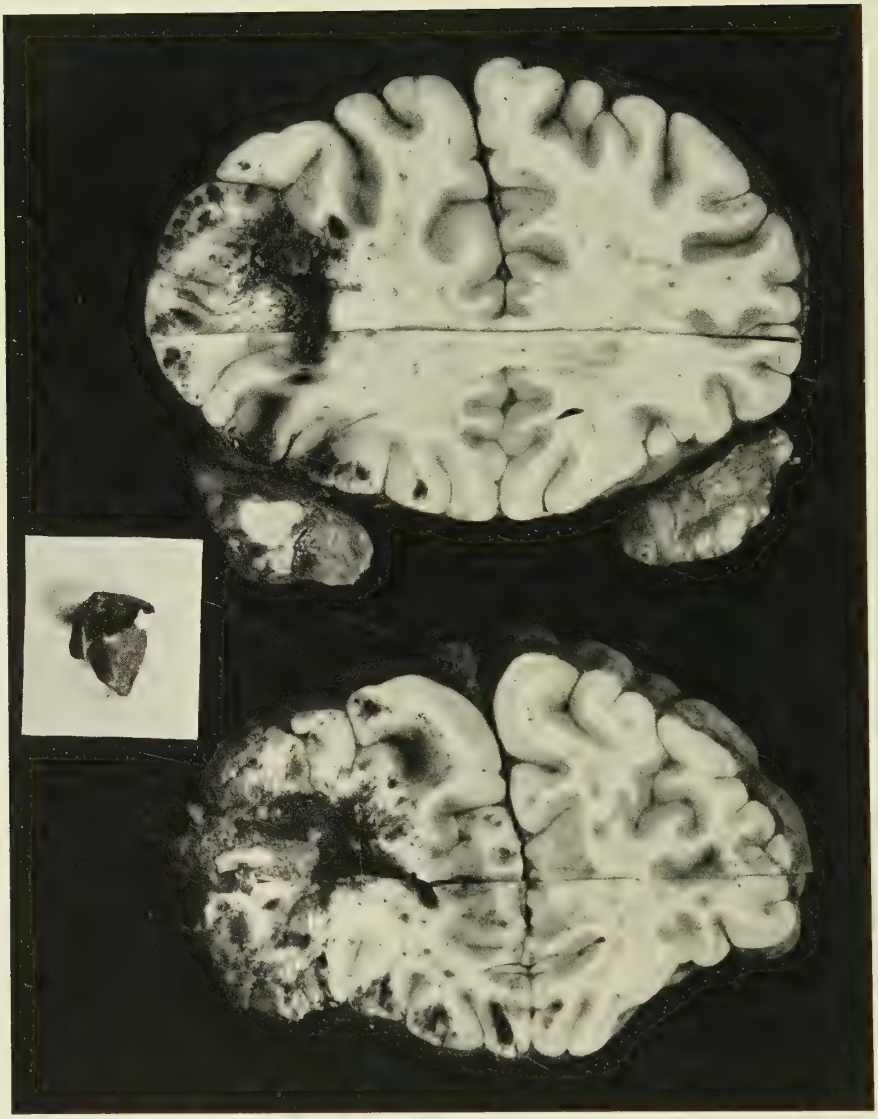
22 c

Fig. 22. a. Two gashes from an axe in the forehead. — b. The fracture resulting from the left gash. — c. The same fracture running up into the vault. Fracture in the sutura sagittalis from another gash. Down to the left the upper end of a segment fracture from a blow with the blunt end of the axe.

23 a

23 b

Fig. 23. Splinter injury. No explosive effect to the skull. — a. X-ray photograph. The splinter and numerous accompanying bone splinters. — b. Upper slice: Bone splinter in lacerated brain substance. Middle slice: Arrow indicates the track of the splinter. Under slice: The splinter in the membranes next to the left tractus opticus. The slices viewed from in front.



24

Fig. 24. Splinter injury. Unilateral explosive effect to the skull. Shot track wider than the projectile. Copious bleeding in the direction of the skull injury. In the white square: The splinter.

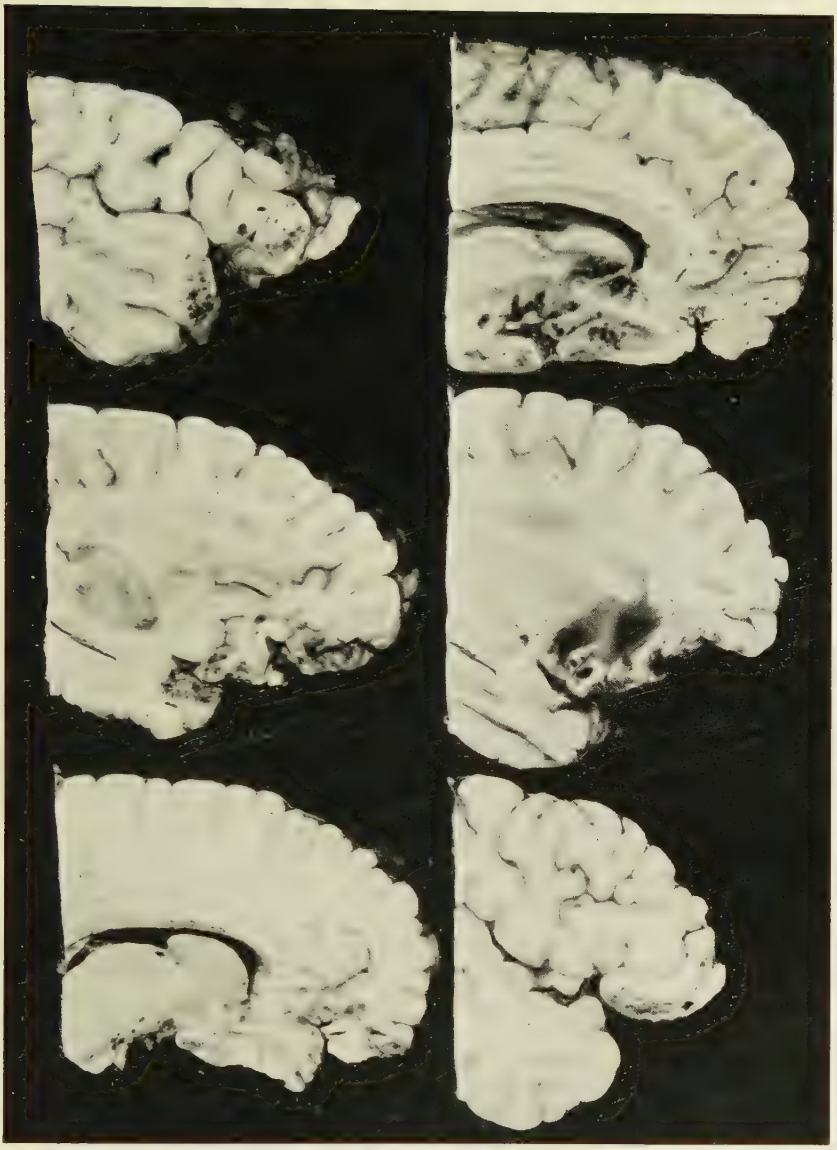


Fig. 25. Pistol-shot injury. Explosive effect to the skull all round. Fissure formation in the inferior parts of the frontal lobes (the two middle slices). Surrounding zone of haemorrhage in the cortex, medulla, and foremost parts of the basal ganglia. Slices viewed from the right.

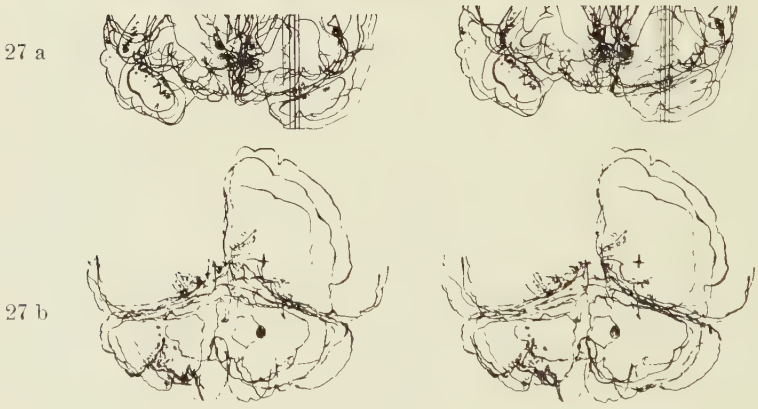
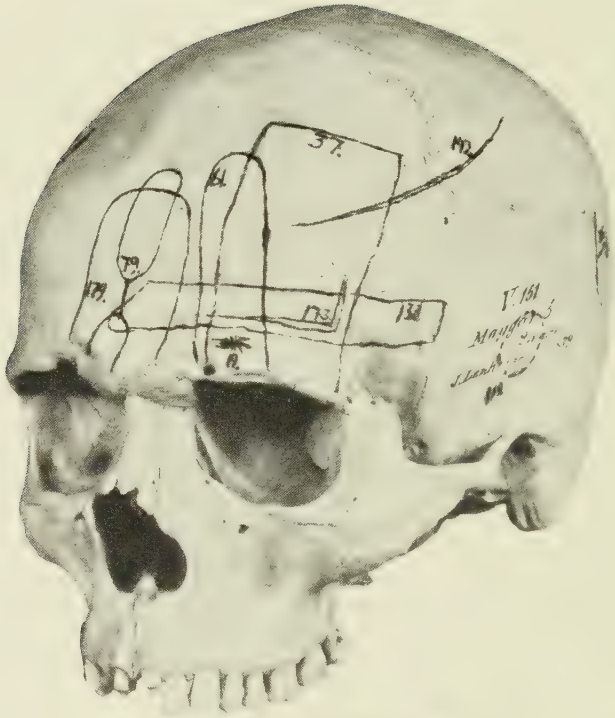


Fig. 26. Atypical meridional injury to the brain. — a. Hernia of cerebellum tissue and fissure formation in the pons along it. — b. Sphere haemorrhages in the pons round the fissure. — c. Sphere haemorrhages under the pendule of the hernia.

Fig. 27. Atypical cortex injuries. — a. Scattered cortex injuries at the opposite pole; among these patches in the medial sides of the frontal lobes. — b. Patches of fine perivascular haemorrhages in the medial sides of the occipital lobes. In addition, meridional injury to the cerebellum; a haemorrhage in the pons.

Fig. 28. Localization of impacts of plane violence. (Figures = case numbers.) Dots and small figures: Exactly described localization. Large figures: Approximatly described localization.

29 a



29 b

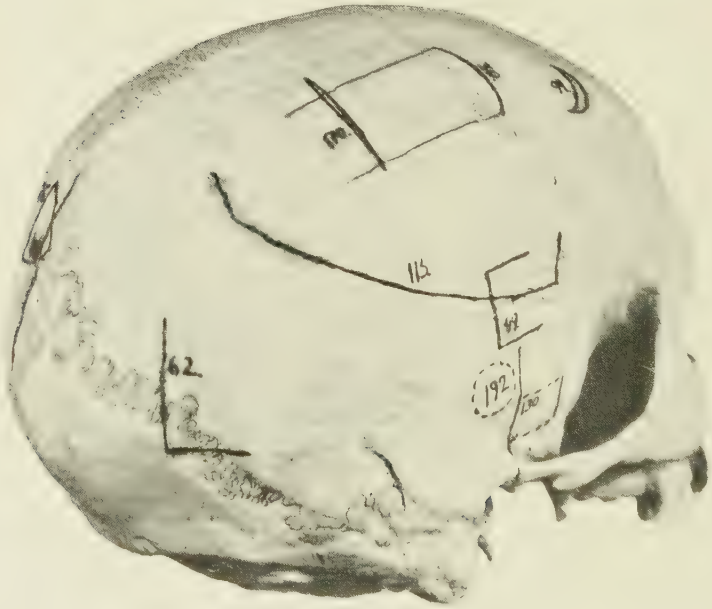
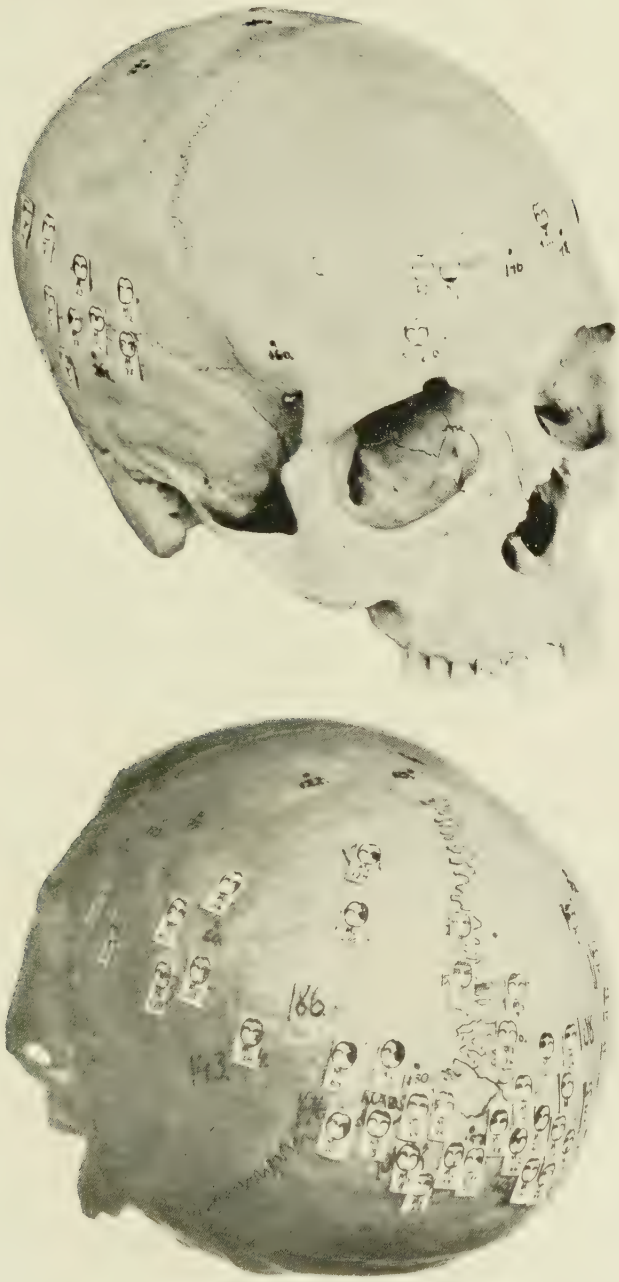


Fig. 29. Localization of impacts of shaped violence. Each one indicated by its shaped surface injury and its case number.



30 a

30 b

Fig. 30. Impacts from plane violence with opposite-pole injuries, marked on the same skull as in fig. 28.

Localization and magnitude of the brain injuries and type of fracture indicated by the individual schemes:

Type *a*: Dotted.	No direct fracture:	O fr.
Type *b*: Straight inner limit.	Meridional fissure:	$M_{1, 2,}$ and $_3$.
Type *c*: Convex inner limit.	Globus fracture:	G.
For explanation see text p. 66.	Sector fracture:	DM.

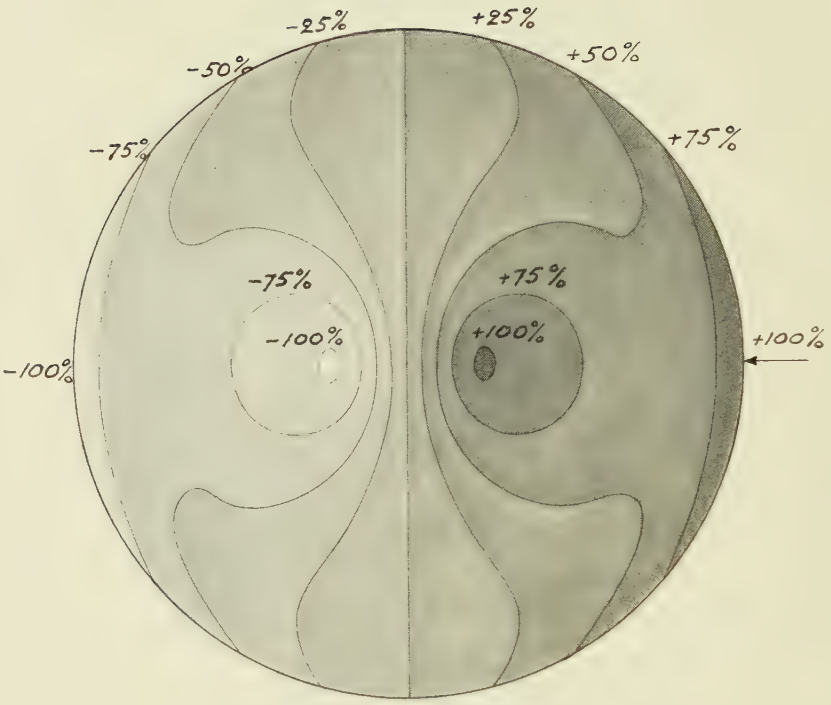


Fig. 5, belonging to the supplement (by Anzelius).
»Isolines», indicating highest (positive) and lowest (negative) pressure during the first quarter of a whole oscillation period in an enclosed spherical liquid mass under certain assumptions (see supplement, case $f(r) = r^6$). Diametral plane.

General explanations of the figures.

a. Stereoscopical pairs of pictures are transposed (the right eye's picture to the left and *vice versa)* and should be looked at with crossed lines of vision. Most people can do this after a little practice without a stereoscope. For true reconstruction of the shape of the objects the pictures must be seen at a distance of 27 cm.

b. The schemes of injuries give the outside of the vault and the inside of the base. On the outside are seen the surface injury (stampings: squared; scrapings: ruled; wounds with their shape: black and red: undermining: dotted), bleeding under the scalp (red), and fractures (black lines). On the inside are seen fractures (black lines), laceration of the dura (black. dotted), and brain injuries (red. Lacerations: shaped, all red; perivascular haemorrhages: short lines; sphere and ring haemorrhages: round spots). Further explanations in the individual schemes.

(but never in the cortex) groups of sphere and/or ring haemorrhages. These are more sharply demarcated than the perivascular haemorrhages, and are always round on the section, irrespective of the direction of the cut, so that they can easily be distinguished even with the naked eye. Microscopic controls (Fig. 16 b and c.), some with section series, have been made in a number of cases. There is, of course, nothing to prevent an injury of this kind being surrounded by a cortex injury with perivascular haemorrhages.

In two cases belonging to the anatomical material there are injuries at the opposite pole that, practically speaking, only concern the medulla. One of them (Fig. 13 a and b.) is the type that is particularly deep, with concentric fissure formations and sphere and ring haemorrhages. The other begins as a rupture in the cortex and continues as a blood-filled cavity, surrounded by a thin layer with irregular haemorrhages in the medulla. (It is localized at the tip of the right frontal lobe, furthest down medially, and on the left side there is a symmetrical injury, similar but much smaller.)

The injuries to the cerebellum (Fig. 15 b.) are considerably rarer: three cases in the statistical material, two in the anatomical. Both the last two are small and show haemorrhages in the cortex, of perivascular type in the broad molecular layer, but most like sphere haemorrhages (diapedesis) in the granular layer. Streaks of haemorrhage continue a short way down in the white substance.

Common to all these very different injuries is, as has been said, their localization at or round the opposite pole, but their extension sideways and downwards varies greatly, and large zones within the areas in question may appear quite unhurt to the naked eye. This capriciousness is difficult to reconcile with the idea of a real counter-stroke, as also with the 'pressure gradient theory' advanced by Goggio (1941). In the latter case we ought to get a limit for the injuries corresponding to a certain value for the calculated pressure below atmospheric, that is to say a plane at right angles to the axis from impact pole to opposite pole (= the direction of the impact).

The descriptions of the different cerebral injuries resulting from blunt violence to the free head that are found in the medico-legal records do not allow of so detailed a division as has been given above. Nevertheless they are full enough to allow of a

division in two respects: 1) It is always possible to get an idea of how many of the lobes have been affected by the injury. 2) A certain idea of the abundance of the haemorrhage and the depth of the injury can always be got. The following classification is therefore used in the statistical treatment: a) Small injuries only showing scattered haemorrhages in the cortex. b) Medium injuries showing abundant bleeding and laceration in the cortex. c) Large injuries showing bleeding and sometimes laceration more or less deep down in the medulla also.

There are sometimes fairly large haemorrhages in the interior of the brain, but it is more usual to find groups of small ones, and occasionally a more diffusely spread type, all agreeing with Hewett's already quoted description. Such injuries are observed in 28 cases in the statistical material, and in 9 in the anatomical. It is plain that the ordinary autopsy technique on an unfixed brain incurs the risk of overlooking the small haemorrhages often in question here — at any rate if they are not immediately visible under the ependyma of the ventricle walls. Such a risk can be discounted in the anatomical material, where the investigations have been made systematically with parallel sections (considerably closer in the brain stem than in the cerebrum). This material shows 7 cases with haemorrhages of the type described by Berner, i. e. groups of small diapedesis haemorrhages under the anterior half of the fourth ventricle and round the aqueductus Sylvii (Fig. 6, 7 b, 12 b and 27 b.). The haemorrhages spread more or less far down into the pons. As well, there are two cases with numerous, more scattered small haemorrhages in the central parts of the cerebrum and in the basal ganglia. In one case (Fig. 4 a and b.), following violence to the left in the forehead, there is a denser group medial to the posterior horn of the right lateral ventricle, and a sparser and more extended group with its centre in front of and somewhat to the left of the genu corporis callosi. The other case (Fig. 5.), after violence to the right temple, has small irregular haemorrhages in the putamen and thalamus, and also in the corpus callosum and adjacent parts of the cortex on the under side of the frontal lobes and the tips of the temporal lobes — i. e. they are collected within an approximately hemispherical surface; corresponding to this we see, on both sides and more

or less symmetrically, fissure formations within the putamen, surrounded by haemorrhages.

2. In blunt violence to the supported head we get very severe damage to the brain as well as to the bone. Thus, injuries sustained by persons run over are shortly described thus: The brain completely crushed, resembles a bloody pulp or the like. In those cases where the circumstances and the surface injuries indicate blows to a supported head or crushing which ceased before having its full effect, injuries are found on the brain corresponding to depression fractures, but in none of the 5 cases are there injuries either at the opposite pole or in the interior of the brain.

3. The gunshot injuries to the brain can be classified as follows: 1) The two shot injuries. One completely destroyed the right half of the brain, while the left half was, largely speaking, uninjured. The other caused superficial crushing in the basal portions of the frontal and temporal lobes. 2) A bullet injury from a 6.35 mm pistol. Here the brain was rotten and allowed of no detailed investigation. 3) Bullet and splinter injuries (brain not rotten). Ten cases with one track and two cases with two or more of them. These cases can easily be divided up into two sub-groups, one (Fig. 23.) showing shot canals in the brain substance with fairly smooth sides, with a calibre corresponding approximately to that of the projectile, and with only slight bleeding round about. The other group (Fig. 24 and 25.) shows shot canals in the brain substance with very ragged walls, with a calibre considerably exceeding that of the projectile and surrounded by a broad zone of numerous large and small haemorrhages in the cortex, the medulla, and possibly in the basal ganglia also.

It is immediately apparent that it is the cases with explosive effect on the skull that also show the severe injuries round the shot track. When the track is central, both explosion fracture and brain injury are distributed round it on all sides (Fig. 25.). With a more tangential track, the fracture system and the injury to the brain both collect unilaterally in the direction of the least resistance (Fig. 24.). The cases with smooth tracks show either no explosive effect on the skull at all, or else merely the slightest degree of it in the shape of the orbital roof fractures.

4. In no cases of edged violence were the injuries other than those directly following on from the wound (through scalp, bones, and

membranes). The injury to the brain substance also has clean-cut, smooth walls, and surrounding tissue is free from haemorrhage patches. Nor is there any very abundant collection of blood in the actual injury, for even if a cut or gash bleeds copiously, the blood is not retained but can flow out freely through the wound. The depth of the wound depends on the strength of the violence and the sharpness of the edge. The author's material contains cases with an almost completely split brain.

c. **Casuistics.**

A. *Typical cases.*

1. Blunt violence to free head.

a. Cases without direct fracture.

Case 134. Specimen 2 (E. S.).[1] Man, 53 years. Cyclist run into obliquely from behind on the left by car, 100 km/hr. Stampings in the skin over both ossa zygomatica. Died after nearly 3 days' unconsciousness from pneumonia. No fracture. Brain injury: See fig. 13 a and b. The case is diagnosed in the record thus: Roof of car against left cheek, fall to the ground against right cheek. The localization of the brain injury points to the serious impact's having been far down to the left in the back of the head, however.

Spec. 24 (E. S.). Man, 25 years. Driver of car that skidded at a high speed and hit a tree with its right side. Dead from brain and bodily injuries after 1—2 hours. Cut in the right temple and severe and extended bleeding under the integument at this spot. No fracture. Brain injury: See fig. 5.

Case 180 (H. S.). Man, 24 years. Passenger on a heavy-weight motor-cycle that ran into a light-weight motor-cycle. Fall to the ground with the back of the head foremost. Dead from pneumococcal meningitis after 26 days. Healing contusion to the left in the occiput. Fracture of the orbital roof: See fig. 14. No brain injury.

b. Cases with short fissure.

Case 142. Spec. 4 (E. S.). Woman, 52 years. Was sitting to the right of the driver in the front seat of a car, which ran straight into an omnibus at 60 km/hr. Forehead hit a rim in the front of the car. Dead from cerebral symptoms and pneumonia after more than 3 days. Surgically treated wound to the left in the forehead. Short fissure. Brain injury: See fig. 4 a and b.

c. Cases with meridional fissures.

Case 233 (H. S.). New-born girl, weight 3,500 gm. Precipitate delivery in outside earth closet. The child fell down on the cement floor, where it

[1] Indicates who performed the autopsy. E. S. = the Chief, H. S. = the author.

was left without attention. Dead in a short time. A number of skin grazings without deep injuries. Otherwise copious bleeding under uninjured skin. A fracture system of meridional type: See fig. 1. Small subdural haemorrhage. Brain uninjured.

Case 174. Spec. 17 (H. S.). Man, 65 years. Was running over the road and run into from the left by a car, 30 km/hr. His back to the radiator. Severe internal injuries. Fall to the road with the right side of the sinciput foremost. He then rolled along the ground. Death from the brain and bodily injuries after 1 hour. Surface injuries: See fig. 7 a. One meridional fissure: See fig. 7 b. Slight injury at the opposite pole: See fig. 7 b and c. Two small subependymal haemorrhages in the bottom of the anterior of the fourth ventricle.

Case 206. Spec. 37 (E. S.). Man, 35 years. Fell to the ground from the cabin of a skidding lorry with the back of the head foremost. Died from the brain injury after 1 hour. Superficial and deep injuries: See fig. 8. The part of the skull base demarcated by the incomplete ring fracture was clearly depressed into the cavum cranii.

Spec. 49 (H. S.). Man, 22 years. Sweep, who fell from the roof of a four-storey house to the asphalt yard back foremost. Died immediately from the brain injury and aspiration of blood. Superficial and deep injuries: See fig. 9 a. Fig. 9 b shows a cross section through the brain at the opposite pole.

Case 210. Spec. 42 (H. S.). Man, 29 years. Intoxicated. Fall down the cellar stairs. Occiput (to the left) against the worn edge of the bottom step (of cement). Died after 2 hours from the brain injury and aspiration of vomited contents of stomach. Surface injuries: See fig. 10 a. Meridional fissures together with a cross break and meridional injuries to the dura: See fig. 10 b. Brain injury along the upper meridional fissure and at the opposite pole: See fig. 10 c.

Case 165. Spec. 16 (E. S.). Man, 46 years. Intoxicated cyclist, upsetting on a downhill slope. Fall to the ground with the right side of the occiput foremost. Died after 3 days from the brain injury. Contusion to the right in the occiput. Meridional fissures. Brain injury at the opposite pole: See fig. 11 a—d.

Spec. 47 (H. S.). Woman, 86 years. Spontaneous cerebral haemorrhage with consecutive fall on the cellar stairs (4 steps). Dead from the brain injuries and purulent bronchitis after 2 days. Stamping towards the front in the right temple. Meridional fissure down through the anterior of the right fossa media and sella turcica, ending in the roof of the left middle ear. The dura uninjured. Small meridional injury in the top of the right temporal lobe. Opposite-pole injury: See fig. 12 a. Patches of haemorrhage in the interior of the brain: See fig. 12 a and b.

Spec. 28 (E. S.). Man, 45 years. Cyclist run into from the side by a car, speed unknown. Fall to the paved road with occiput foremost. Died after 4 hours from the brain injury. Contusion to the right in the occiput. »Two gaping fissure lines towards the foramen magnum». Fairly extended deep cortex injury at the opposite pole on the under sides of the frontal lobes,

on the tip of the left temporal lobe, and on the over side of the tip of the right temporal lobe (in towards the fossa Sylvii). Large haemorrhage patch in the pons: See fig. 6.

d. Cases with globus fracture.

Spec. 48 (H. S.). Man, 66 years. Cyclist, run into straight from the left by omnibus, 30 km/hr. Thrown 20 metres forward and fell to the paved road with back and right side of the occiput foremost. Died immediately from the brain injury and aspiration of blood. Surface injury and fracture system: See fig. 17. The dura extensively lacerated along the fracture lines over the left occipital lobe and over the left hemisphere of the cerebellum. Extended laceration of both these parts of the brain. Numerous perivascular haemorrhages in the cortex on the inner side of the occipital lobe and on the under sides of both temporal lobes. No injuries at the opposite pole or in the interior.

Spec. 46 (H. S.). Man, 46 years. Intoxicated. Fall from a railway train. Found on the embankment. Died after 12—24 hours from the brain injury and aspiration of blood. Surgically treated wound in front to the right in the sinciput. Extremity fractures. Small globus fracture: See fig. 3. A number of loose fragments removed surgically. Along the longer meridional fissure the dura and under side of the right frontal lobe were lacerated: Fig. 3. No injury at the opposite pole or in the interior.

Case 164. Spec. 14 (E. S.). Man, 31 years. Light-weight motor-cyclist, who ran into a pedestrian and fell to the road with the left side of the face foremost. Died after 1 hour from the brain injury and aspiration of blood. Stamping to the left in the forehead. Globus fracture. The dura severely lacerated over the left frontal lobe and the front part of the left temporal lobe. These parts of the brain were also severely injured. Perivascular haemorrhages in the cortex of the under side of the right frontal lobe (meridionally). Limited, deep cortex injuries at the opposite pole on the boundary between the right temporal lobe and occipital lobe of the cerebrum and on the cerebellum, furthest out to the right. Microscopic examination of the opposite-pole injuries to the cerebrum (See fig. 15 a) and to the cerebellum (See fig. 15 b).

Spec. 25 (S. W.). Woman, 27 years. Domestic servant, who fell from a window in the second storey into the paved yard. Died after 2 days from the brain injury and complicating pneumonia. Bleeding under uninjured skin. Globus fracture with its centre in the left temple. The dura not mentioned. Sparse perivascular haemorrhages along the fracture lines. Cortex and medulla injuries at the opposite pole, on the outer side of the right temporal lobe with fissure formations right into the temporal horn: See fig. 16 a. Microscopic examination: See fig. 16 b and c.

e. Cases with sector fracture.

Case 1. Museum specimen (E. S.). Man, 33 years. Murder. Repeated blows with the blunt end of a large axe. Found dead from the brain injury.

Distinctly shaped depression fracture to the right in the occiput with a meridional fissure continuing down to the foramen magnum: See fig. 18. The brain under this injured. Otherwise no cerebral injuries.

Case 133. Museum specimen (E. S.). Man, 50 years. Intoxicated, run into by train. Hit in the forehead to the left by the projecting metal edge in front of the electric engine. Died after a short time from the brain injury and internal bleeding. The surface injury surgically treated and numerous bone fragments removed. The specimen shows the distinct, shaped fracture opening that widens inwards and continues with 3 fissures: See fig. 19 a and b. Dura and brain lacerated under the fracture opening. Otherwise no cerebral injury.

Spec. 36 (H. S.). Man, 20 years. Free fall 8 metres. Died after 2 days from the brain injury. Stamping to the left in the forehead. Three meridional fissures with depression of intermediate bone, and laceration of dura and brain: See fig. 2. Otherwise no cerebral injuries.

f. Cases with segment fracture.

Case 170. Museum specimen (E. S.). Man, 66 years. Cyclist, run into from behind by car. Hit high up in the right temple by the upper hinge of the right front door. Died after 24 hours from the brain injury. Scalping injury. Segment fracture: See fig. 20 a and b. Laceration of dura and brain by penetrating fragments of bone: See fig. 20 c. Otherwise no cerebral injuries.

Case 119. Museum specimen (E. S.). Man, 26 years. Got a blow of a fist in the left temple during a fight. Gradually increasing symptoms of cerebral pressure. Died after 4 days from extradural haemorrhage. Bleeding under uninjured skin. Small depression fracture in the very thin squama temporalis: See fig. 21. Otherwise no deep injuries.

2. Edged violence.

Case 204. Museum specimen (C.-G. A.). Man, 16 years. Murder with an axe. According to the confession of the murderer, the sharp gash in the middle of the sinciput was inflicted first, from behind, and the other gashes and the blow with the blunt end after the victim had fallen to the ground. He was found dead from the brain injury. A sharp gash through cap, integument, and skull in the middle of the sutura sagittalis (See fig. 22 c) and into the sinus sagittalis, but no further. Two gashes in the forehead: See fig. 22 a. The left continued through the skull (See fig. 22 b and c), and the dura, and deep into the interior of the brain. Segment fracture down to the left in the occiput, reproducing the shape of the blunt end. Under this the dura was lacerated with bleeding in the membranes. Otherwise no cerebral injuries.

3. Gunshot.

Spec. 51 (H. S.). Man, 26 years. Multiple injuries due to splinter from exploding tank-mine. Dead after a short time from the brain injury and

internal haemorrhage. Entrance wound over the inner part of the right eyebrow, with round holes in the anterior and posterior walls of the frontal cavity. Shot track through the under part of the right frontal lobe with a number of secondary tracks of accompanying bone splinters. The splinter was found in the membranes by the left tractus opticus: See fig. 23 a and b. Very slight bleeding round the shot tracks. The splinter's own track has the splinter's calibre: See fig. 23 b, middle slice. No explosive effect on the skull. Otherwise no injury to the brain.

Prep. 52 (H. S.). Man, 27 years. Multiple splinter injuries from the same accident. The splinter injuries to the body otherwise considerably less than in the preceding case. Died after 2 days from the brain injury. The entrance wound to the right in forehead was surgically treated, bone splinters and prolapsed brain substance removed, dura and skin primarily closed. Explosive effect on the right anterior part of the vault: Several loose fragments of the os frontale; from the defect proceeds a coarse bone fissure up to the right tuber parietale where it branches in the shape of a T. Both the branches gradually taper off and end before reaching the boundaries of the os parietale dex. Large shot canal with fissure formations radiating from it, surrounded by ragged brain substance suffused with blood. The shot canal narrows towards the back and ends at the surface of the right parietal lobe, where there is a large splinter: See fig. 24. From the shot canal and out towards the exploded part of the skull there is copious bleeding in both cortex and medulla: Unilateral explosive effect: See fig. 24.

Case 209. Spec. 44 (H. S.). Man, 36 years. Suicide from close discharge with 9 mm pistol in the right temple. Dead after 2 hours from the brain injury. Characters of a close discharge round the entrance wound in the right temple. Large canal straight through the head corresponding to the place for the orbital roofs. The skeleton of the face extensively smashed. Both eyes are exploded and emptied of their content. Three fissures run up through the vault: 1. From the entrance hole via the sutura coronaria up to the anterior end of the sutura sagittalis. 2. From the glabella, proceeding from the splintering along the shot track, straight up through the os frontale near to where the first fissure ended. 3. From the exit hole obliquely upwards and backwards through the os frontale and parietale to the posterior end of the sutura sagittalis. Nearest the shot canal there are on the under side of the frontal lobes fissure formations up in the brain substance; immediately round this a zone without bleeding; outside this zone a broad zone of haemorrhages of various extent in cortex, medulla, and the foremost parts of the basal ganglia; beyond this the brain is macroscopically unchanged. Explosive effect all round: See fig. 25.

B. *Atypical cases.*

Case 188 (H. S.). Girl, 8 years. Running; was run into from the right by car, 60 km/hr. Plane violence to the right between temple and occiput, against the car or in the fall to the road. Died immediately from bodily

injuries (*inter alia* severance of the cervical vertebrae and spinal cord). Stamping immediately below and behind the right tuber parietale. Meridional fissure along the inside of the right os temporale, up to the left foramen opticum. Dura and brain uninjured everywhere.

Case 186 (E. S.). Girl, 8 years. Running; was run into from the left by a car, 80 km/hr. Fall to the road with the left part of the occiput foremost. Died after 6 days from extradural haemorrhage. Contusion to the left in the back of the head. Meridional fissure, partly running through the sutura parieto-squamosa. Here there is the injury to the meningeal arteries. The brain is uninjured.

Spec. 45 (E. S.). Boy, 7 years. Hung on behind an omnibus and fell off. The occiput struck the bar of the trailer. Died immediately from the brain injury. Shaped wound in the occiput, immediately to the left of the middle line. Meridional fissure along the inner side of the left os temporale, running forward through the sella turcica to the right ala parva. Laceration of the dura in the posterior cranial fossa along the fissure. Hernia of cerebellum tissue and fissure formation in the pons along it: See fig. 26 a. Sphere haemorrhages under the pendule of the hernia and round the fissure in the pons: See fig. 26 b and c. The brain otherwise uninjured.

Spec. 22 (H. S.). Man, 64 years. Free fall 2 metres. Back of head against the ground. Died after 2 days from the brain injury. Palliative trephination. Stamping over the left tuber parietale. Meridional fissure along the inner side of the left os temporale up to the right foramen opticum. The dura uninjured. Large cortex and medulla injury at the opposite pole in the right frontal and temporal lobes. A group of small haemorrhages under the anterior part of the fourth ventricle. In addition there is a lengthy, 5 cm long, sagittally placed patch of haemorrhage in the cortex and adjacent parts of the medulla on the under side of the right temporal and occipital lobes, directly under the temporal and posterior horn of the right lateral ventricle.

Spec. 38 (E. S.). Woman, 85 years. Walking; run into by cyclist. Fall to the ground. Died after 2 hours from the brain injury. Contusion to the left in the occiput. Meridional fissure through the left fossa cranii posterior. Laceration of the dura and cerebellum along the fissure: See fig. 27 b. Scattered cortex injuries at the opposite pole in the frontal and temporal lobes, among these symmetrical patches in the medial sides of the frontal lobes: See fig. 27 a. A haemorrhage the size of a pea in the pons. In the cortex of the brain on the inner sides of the occipital lobes there is an extended patch of very fine perivascular haemorrhages: See fig. 27 b.

C. *Doubtful cases.*

Case 167 (E. S.). Man, 30 years. Heavy-weight motor-cyclist, who skidded and upset. Extended grazing in the right part of the face in horizontal streaks. Horizontal clean-cut wound in front in the right temple. Under this there is copious bleeding under the integument, and globus fracture. Beneath this copious bleeding between the pia and arachnoid and in the

cortex cerebri. Superficial laceration and bleeding in the cortex at the end part of the left temporal lobe. No haemorrhages in the interior of the brain. Diagnosed in the record as a blow against a tree-trunk, in which there was a nail; his cap was hanging on this. The wound in the temple, which was caused by the nail, cannot explain the extended bleeding under the integument, however. This case is moreover the only one where a plane, tangential injury is said to have given deep injuries. Instead the case should be taken as two applications of violence to the same region: the grazing against the tree and a fall to the ground with a surface injury in the form of bleeding under uninjured skin.

Case 198 (E. S.). Woman, 31 years. Walking; run into from behind by lorry, 40 km/hr. Scalping injury in the anterior part of the sinciput, with deep undermining behind; gravel from the road penetrating deep in. Large ring fracture forcing apart the sutura lamboidea and running through both the middle ears, and the sella turcica. At the last spot the dura is lacerated and the brain injured in the bottom of the third ventricle. Otherwise no brain injury. The case is diagnosed as a ring fracture (due to the body's inertia) in the fall with the sinciput against the road. As the injury in the sinciput is markedly tangential, it can hardly give any deep injuries. The case is moreover reputed to be the only one of ring fracture not due to the junction of two meridional fissures. There is probably a non-registered plane injury in the occiput, at the tip of the sutura lamboidea. This is all the more likely as there is a dent in the bonnet of the lorry, probably fitting a fall against it with the occiput.

Case 127 (E. S.). Man, 72 years. Cyclist, who came out from a side road and ran right into a lorry, 35 km/hr. Forehead against the upper edge of the front wall of the platform, followed by fall to the ground. Surgically treated wound in the forehead. »Extensive fracture in the thin roof to both orbits. The dura uninjured. Moderate bleeding under dura, corresponding both to the left frontal lobe of the brain and to both its occipital lobes; at these places there is also bleeding in the pia and arachnoid. On incision a surface injury, corresponding to this, was also encountered in the cortex cerebri». The brain otherwise uninjured. The injuries are described in the record as all being caused by the violence to the forehead. This is the only case where there is injury at the impact pole (in the left frontal lobe) without depression fracture. There are probably two applications of violence with deep injuries: 1. The blow against the edge of the lorry platform with opposite-pole injury in the tips of the occipital lobe. 2. Fall to the ground (without visible, or perhaps not registered, surface injury) with opposite-pole injury in the left frontal lobe and orbital roof fractures at the opposite pole.

Case 18 (E. S.). Girl, 4 years. Running; run into by car, speed unknown. Fall to the road. Bleeding under uninjured skin round the right tuber parietale. Meridional fissure through the right middle ear, sella turcica towards the left middle ear. Meridional injury to the dura and lower part of right temporal lobe: »Contusion the size of a half-crown of the gray substance. Similar, slighter contusion at the corresponding place on

the left side.» This is the only case with opposite-pole injury in a child (under 10 years of age). In this case the autopsy was done in a medico-legal form for the purpose of instruction. The record is made by a student.

Case 163 (E. S.). Man, 36 years. Intoxicated. During a quarrel he got a blow from a heavy wrench behind the right ear (near the tip of the processus mastoideus); the man inflicting the blow was left-handed. Here there is also a right-angled, shaped stamping, corresponding to the striking surface of the wrench. As well, there is a small haemorrhage under uninjured skin in the left temple. Skull uninjured, dura intact. »Bleeding in the pia and arachnoid to a level with the sawn incision, increasing greatly down along the basal cisterns. Brain uninjured. No bleeding place found in the membranes.» The case is the only one where a blow with a free weapon gave deep injuries without fracture at the same time. This gives reason to suspect that the copious subarachnoid bleeding is spontaneous and not traumatic, even though, in this situation, it can have been provoked by the act of violence.

3. Statistical investigations.

a. The relation of the different injuries resulting from blunt violence to the free head to one another.

This group has already been divided up into injuries from plane and from shaped violence. This division will be adhered to hereafter, also, since this difference has proved itself to be of fundamental importance for the differences between the different types of injury.

In many cases it is possible to determine the form of violence (plane or shaped) from the surface injury (Tab. 10.) alone. When tangential, plane violence gives grazings, when non-tangential it gives either haemorrhage under uninjured skin or 'stampings' or contusion wounds in the skin. Applied at right angles, shaped violence gives either surface injuries agreeing with those got from plane violence, or shaped wounds straight down through the integument; oblique shaped violence gives more or less pronounced scalping injuries.

The type of fracture set up (Tab. 11.) depends wholly on the shape and strength of the violence applied. Thus fractures from plane violence are mainly of the types: 'Small fissures' or 'Meridional fissures'. Shaped violence usually gives segment fractures or sector fractures. The severest form of fracture of the skull, i. e. globus fracture, can on the other hand be caused by both

TABLE 10. *Group 'Blunt violence to free head. One system of deep injuries'. According to the connected surface injury.*

Surface injury	Plane violence			Shaped violence			Plane ? shaped			Totals		
	Brain only	Other	Total	Brain only	Other	Total	Brain only	Other	Total	Brain only	Other	Total
Bleeding under uninjured skin	16	18	34	1	1	2	1	1	2	18	20	38
Stamping	14	14	28	1	1	2				15	15	30
Contusion wound	11	9	20	2		2		1	1	13	10	23
Shaped wound				7	7	14				7	7	14
Scalping with fracture				3	1	4				3	1	4
?	5	2	7		2	2	2	1	3	7	5	12
Total	46	43	89	14	12	26	3	3	6	63	58	121

'Brain only' = Death from brain injury alone.

'Other' = Death from other injury or disease (alone or together with brain injury).

plane and shaped violence. These rules have only a few exceptions in the material. Thus there are two cases of plane violence to the forehead giving sector fractures as a result of the previously discussed mechanism with the fragile orbital roofs. There are two further cases where shaped violence has not given a depression fracture, but there is of course no reason why a 'shaped' instrument could not be so nearly plane as to act as plane violence.

The injuries to the dura (Tab. 13.) are shown to depend entirely on the fracture type produced: Only depression fractures gives injuries at the impact pole; only along meridional fissures do we get the meridional injuries to the dura mater. The surface injuries to the dura that are combined with lesions to the arteries, and which cause extradural bleedings, occur in fractures of different sorts, but as a rule in small breaks passing over the arterial sulci. The typical picture of extradural haemorrhage is got, that is to say, only when the dura is not injured right through so that the haemorrhage set up is shut off between the bone and the dura.

When the dura is injured meridionally or at the impact pole, injuries of less or more far-reaching nature are most often ob-

TABLE 11. *Group 'Blunt violence to free head. One system of deep injuries'. According to type of fracture.*

Type of fracture		Plane violence			Shaped violence			Plane? shaped			Totals			Ring fr.	Fr. of orb. roof	
		Brain only	Other	Total	Brain only	Other	Total	Brain only	Other	Total	Brain only	Other	Total		at imp. pole or merid.	at opposite pole
No direct fracture		5	8	13		1***	1		1	1	5	10	15		1***	2
Short fissure		1	4	5		1	1		1	1	1	6	7		1	
Meridional fissure		32	26	58		1	1	1	1	2	33	28	61	5	5	4
Globus fracture		5	3	8	4		4	1		1	10	3	13	3	1	1
Sector fracture		1*	1*	2	7	3	10				8	4	12		6	
Segment fracture					2	5	7				2	5	7		1	
Ring fracture		1**		1							1		1	1		
?		1	1	2	1	1	2	1		1	3	2	5			
Total		46	43	89	14	12	26	3	3	6	63	58	121	9	15	7
Group 'Meridional fissure':	1	19	20	39							19	20	39		2	2
	2	9	3	12		1	1	1		1	10	4	14	3	1	2
Number of fissures in each case	3 or more	4	2	6					1	1	4	3	7	1	2	
	?		1	1								1	1	1		

* Impacts to the forehead. ** Case 198 (p. 74). *** Case 127 (p. 74).

TABLE 12. *Group 'Blunt violence to free head. One system of deep injuries'. Surface injury — Type of fracture.*

Surface injury	No dir. fract.	Short fiss.	Merid. fiss.	Globus fract.	Sector fract.	Segm. fract.	?	Total
Bleeding under uninjured skin	8	3	21	1	2	1	2	38
Stamping	4	2	18	4	1	1		30
Contusion wound	1	1	16	2	3			23
Shaped wound	1			3	5	4	1	14
Scalping injury with fracture			1	1	1	1		4
?	1	1	5	2			3	12
Total	15	7	61	13	12	7	6	121

TABLE 13. *Group 'Blunt violence to free head. One system of deep injuries.' Type of fracture — Injuries to the dura.*

Type of fracture	The dura injured		?	The dura uninjured	Total	Cases with extradural haemorrhage
	at impact pole	merid.				
No direct fracture				15	15	
Short fissure				7^{4}	7	4
Meridional fissure		21^{2} **	2^{1}	38^{3}	61	6
Globus fracture	6 + 1*	4 + 1 *	1	1	13	
Sector fracture	10			2	12	
Segment fracture	5			2^{2}	7	2
?	3	1		2^{1}	6	1
Total	24 + 1	26^{3} + 1	3^{1}	67^{10}	121	13

* The same case. Small figures = Cases with extradural haemorrhage.
** Case 186 (p. 73). Case 45: Bleeding both extra- and subdural.

tained on the brain also (Tab. 14.). There are isolated cases when the brain is injured under a depression fracture or along a meridional fissure without laceration of the intermediate dura; on the other hand, there is no case of injury to the brain at the impact pole or meridionally without simultaneous fracture injury of corresponding type.

An analysis of the pia and arachnoid injuries has, as far as this material allows, been made in Section 2 of this chapter.

TABLE 14. *Group 'Blunt violence to free head. One system of deep injuries.' Injuries to the dura — Injuries to the brain.*

Dura injured	Number of cases	Brain ?	Remain. cases	Brain injured			
				at impact pole	merid.	at opposite pole	in the interior
At impact pole	24	4	20	19		4	
At impact pole and meridian.	1		1	1		1	
Meridionally	26		26		21	16	3
?	3		3	1	1	2	
Dura uninjured	67	2	65	2 *	4 **	47	14
Total	121	6	115	23	26	70	17

* Case 127 (p. 74). Case 167: Under a globus fracture.
** All four cases: Along a meridional fissure.

Correlations touched on hitherto are simple and mechanical in nature; nor do they call for any statistical treatment. When, on the other hand, we get on to the correlation between the different main types of injury, the situation is not so simple. There are four main types, as follows:

Localization	Injury to
At the impact pole	Skin, bone, possibly dura, possibly brain.
Meridionally	Bone, very occasionally skin, often dura and brain, in which case practically always simultaneously.
At the opposite pole	Only injuries to the brain (and possibly to the pia and arachnoid).
In the interior	Only brain injuries.

In the subsequent question of working out the correlation between these main types, the brain injury has been selected as character. This injury is, after all, obviously the functionally most important factor, but as well as this the presence of brain

injuries guarantees that injury (at impact pole or meridionally) is fully developed. We can take it that if the occurrence of injuries at the impact pole or meridionally has any decisive influence on the whole of the course of the injury, this would assert itself particularly if the injury got right into the brain.

It must now be noted afresh that the damage to the brain is what is fatal in the injuries, and that an autopsy material must therefore be a systematic selection. To bring home the importance of this we take the following constructed example. A certain violence to the head may cause two different injuries, A and B, which are alone (or combined) fatal and which are set up quite independent of one another, the correlation coefficient $r = 0$. If, on the other hand, these injuries are not set up, the violence to the head will not be fatal. An autopsy material therefore includes only those cases that display either or both the injuries, but *not* those which have escaped the injuries A and B. Instead of r being 0, statistics of the section material will show a negative r, and when the material is sufficiently large this correlation will naturally prove to be statistically significant. This mechanism has, of course, the effect of further strengthening an actual negative correlation (negative r) and weakening an actual positive correlation (positive r).

This risk of systematic selection must actually be incurred in the projected investigation of the connexion between the different main types; the material will therefore be treated with the previously mentioned division into 1) such cases where the brain injury alone proved fatal 2) those where it proved fatal only in combination with other injuries or with diseases, or where this other cause of death alone decided the fatal issue (i. e. either there was no brain injury, or else it was so slight that it could not even contribute to the fatal issue). The first group will hereafter be called 'Death from brain injury' and the second group 'Death from other injury or disease'.

As has already been discussed, the group 'Death from brain injury' will only have injuries above a certain size, and the systematic selection will assert itself fully. The correlation coefficients found within this group will therefore shift towards the negative direction in an indeterminable way. In the group 'Death from other injury or disease' we can also count on slighter, not

fatal skull and brain injuries. If the 'other injuries or disease' were alone responsible for the fatal issue, and if there were no correlation between the incidence and the size of the brain injuries and the other ones, the coefficients found in this group would be the true ones. But the fact is that in this group the brain injuries, too, contribute to the fatal issue, so that the same selection mechanism makes itself felt, though certainly it is not so strong as in the group 'Death from brain injury'. As well as this, we cannot with certainty exclude a connexion between brain injuries and other injuries, but the nature of this connexion cannot *a priori* be determined. A positive connexion is conceivable in that the more severe the accident is, the more and the greater the resulting injuries. But a negative connexion in an autopsy material is also conceivable by means of a selection mechanism of the same kind as was discussed above for different types of brain injuries: The fatal injuries to the brain or to the rest of the body or both together are included, but not the group that only has non-fatal injuries in both these regions. In any case, the connexion between brain injury and bodily injury is probably of secondary importance here.

The result is, then, that the correlations found in the group 'Death from other injury or disease' are closer to fact than those found in group 'Death from brain injury'. If no difference is got between these two groups, we can take it that the selection mechanism can be ignored, and that the coefficients found are the true ones.

The correlation coefficients found are given in table 15. The figures show in the main the theoretically calculated tendency, but the material is not large enough to allow of any certain conclusions. In none of the groups are there significant differences between the group 'Death from brain injury' and 'Death from other injury or disease', and none of the coefficients in the latter group show a statistically significant difference from 0. This is of course particularly important as regards the negative values. The statistically significant coefficients (Impact pole — Opposite pole in the group 'Death from brain injury' and in the whole of the material, and Impact pole — Meridionally in the whole of the material) may be selection effects.

TABLE 15. *Group 'Blunt violence to free head. One system of deep injuries'. Correlation between the different brain injuries.*

	Number of cases	Brain injured (+) or uninjured (−)				
		at impact pole	meridionally	at opposite pole	in the interior	
					+	−
'Death from brain injury'						
Brain as a whole thrown out through the wound	2	+15	+	+		
				−		
Brain rotten	2		−	+5		5
				−10		10
Certain cases	59					
Total	63					
		−44	+13	+11		11
				−2		2
			−31	+24	3	21
				−7	4	3
'Death from other injury or disease'						
		+8	+	+		
				−		
			−	+2		2
Incompletely reported cases	2			−6		6
Certain cases	56					
Total	58					
		−48	+13	+7	1	6
				−6		6
			−35	+21	5	16
				−14	4	10

Correlation between brain injuries	Coefficients		
	Brain only	Other inj. or dis.	The whole material
at impact pole and meridionally	−0.31±0.12	−0.22±0.13	−0.27±0.09
at impact pole and at opposite pole	−0.43±0.12	−0.23*±0.13	−0.31**±0.09
meridionally and at opposite pole	+0.19±0.13	−0.00±0.13	+0.09±0.09
at impact pole and in the interior	−0.21±0.13	−0.19±0.13	−0.21±0.09
meridionally and in the interior	−0.20±0.13	−0.15±0.13	−0.17±0.09
at opposite pole and in the interior	−0.20±0.13	−0.03±0.13	−0.12±0.09

* Tetrachoric corr. −0.47±0.22.

** » » −0.60±0.12.

The two groups 'Death from brain injury' and 'Death from other injury or disease' are not directly comparable, however, as the following analysis will show, at the same time as it will try to make them so as far as is possible. Now, in the constructed example, the one condition was that we had to do with *a certain violence*. But the material includes all types of violence that in any way cause deep injuries. In this respect, too, a selection mechanism asserts itself: The group 'Death from brain injury' will only comprise such violence as is sufficient in itself to prove fatal, whereas the group 'Death from other injury or disease' will comprise all degrees of force at all capable of causing deep injuries, granted that here, too, the grosser violence will be over-represented. (The argument postulates violence to the skull with deep injuries not in themselves fatal).

To find out how the two groups stand in this respect, we shall be using three characters which *a priori* can be thought to be correlated with the strength of the violence, namely, the fracture type, the size of resulting cerebral injuries, and the time elapsing between the act of violence and death.

As the anatomical description and the earlier collocations in this chapter show, the skull injuries fall naturally into two groups, respectively with and without depression (i. e. of bone fragments at the impact pole). This in its turn is connected with the form of the instrument inflicting injury: Plane violence does not give depression, shaped violence practically always does. In each of these two groups there is at once apparent a series of injuries, from small (possibly none) through medium to large, thus:

Without depression: No fracture — Short fissure — One — Two — Three or more meridional fissures.

With depression: Segment fracture — Sector fracture with one — two — three meridional fissures — Globus fracture.

A first division of the two groups according to fracture form (Tab. 11.) already supports the probability of the assumptions made: The small injuries preponderate in the group 'Death from other injury or disease', and the large in 'Death from brain injury'. On the other hand, there appears to be remarkably good agreement as regards surface injuries (Tab. 10), both in the group 'Plane violence' and in the group 'Shaped violence'; this points to the comparability of the groups in respect of causation.

Further to elucidate the extent of the injuries (the strength of the violence) in the two groups 'Death from brain injury' and 'Death from other injury or disease', the frequency and size of the different brain injuries set up have been registered, and then collocated with the different fracture forms. It is first established anew that injuries at the impact pole are not set up except under depression fractures, and that the meridional injuries are only found in association with meridional fissures (as has been mentioned before, the material contains no case of meridional injury to the brain in cases with sector fracture).

The material of depression fractures is so small, however, that no certain differences in the extent of the brain injury (at the impact pole) behind them can be established. Nevertheless, the globus fractures seem on an average to display smaller injuries of this kind.

Nor is it possible as regards the meridional injuries of the brain to establish any statistically significant differences between the different large fracture systems from which such injuries result. This holds both for the frequency of the injuries and for their size.

Injuries at the opposite pole are set up in connexion with all types of skull injuries, but there are plain differences both in frequency and in size (Tab. 16.). They are rare among segment and sector fractures; among globus fractures they occur in half the cases, and in injuries without depression they are very common. There are also plain differences between the different groups among cases without depression as regards frequency and an increasing size of the injuries at the opposite pole in the series given above, but this latter correlation is not statistically significant. With the diminishing frequency in the group 'Globus fractures' there is also a plain decrease in size in the injuries at the opposite pole in such cases where these occur. Among other depression fractures these injuries are so rare that no conclusions as to their size can be drawn.

Table 16 also shows that the injuries at the opposite pole are with statistical significance greater in the group 'Death from brain injury' than in the group 'Death from other injury or disease'. This is true whether one selects the cases where the opposite-pole injury is the only cerebral injury, or takes all cases with such

TABLE 16. *Group 'Blunt violence to free head. One system of deep injuries'.*

Frequency and magnitude of brain injuries at the opposite pole — Type of fracture — Cause of death.

Type of fracture	Number of cases	Brain ?	Cases without injury at opposite pole	Magnitude of the opposite pole injury. Number of cases						Cases with injury at opposite pole (Total)
				a 1	a 2	b 1	b 2	c 1	c 2	
No direct fracture	15^{5}		9^{4}	2	2		1	1^{1}		6^{1}
Short fissure	7^{1}	1	5^{1}			1				1
One meridional fissure	39^{19}		4^{1}	4^{1} *	3	10^{5}	11^{7}	2^{1}	5^{4}	35^{18}
Two meridional fissures	14^{10}		2^{1}	1	1^{1} **	2^{2}	4^{3}	1	3^{3}	12^{9}
Three or more meridional fissures	8^{4}		3			1^{1}	3^{2}		1^{1}	5^{4}
Total (without depression)	83^{39}	1	23^{7}	7^{1}	6^{1}	14^{8}	19^{12}	4^{2}	9^{8}	59^{32}
Globus fractures	13^{10}		6^{5}	2^{1}	3^{2}	1^{1}	1^{1}			7^{5}
Sector fractures	12^{8}	2^{2}	8^{4}		1^{1}		1^{1}			2^{2}
Segment fractures	7^{2}		6^{2}			1				1
Total (with depression)	32^{20}	2^{2}	20^{11}	2^{1}	4^{3}	2^{1}	2^{2}			10^{7}
?	6^{4}	3^{2}	2^{1}				1^{1}			1^{1}
Total	121^{63}	6^{4}	45^{19}	9^{2}	10^{4}	16^{9}	22^{15}	4^{2}	9^{8}	70^{40}

Small figures (exponents)=Cases of the group 'Death from brain injury'.

The magnitude is expressed by a letter and a figure. The meaning of the letters is explained in the text (p. 66). The figure 1=injury to only one lobe. The figure 2=injury to two or more lobes.

* Together with meridional injury to the brain, magnitude b 1.

** » » » » » » » c 2.

Correlation between type of fracture and magnitude of the injury in cases without depression in the whole material, tetrachoric corr. $r=0{,}34\pm0{,}20$.

injuries in a comparison. In the latter case we get in the group 'Death from brain injury' two cases with an opposite-pole injury of the mildest sort, but in these cases the other brain injury or injuries are of a severer kind. It can thus be established that 'scattered haemorrhages in the cortex' do not occur in the cases where the brain injury alone is fatal, but only in cases where other fatal changes are seen (in the brain or elsewhere). The investigation hereby clearly supports the assumption that violence to the skull may give visible deep injuries that are not in themselves fatal.

The third character in the discussion of the strength of the violence was, as has been mentioned, the time elapsing between the act of violence and death (hereafter called 'the time till death'). Here the different, previously described groups of 'Causes of death' obviously assume an altogether different position. In the general survey of the material it is seen (Tab. 6.) how different these times are within the different groups. It is evident that when the cause of death is wholly determined by something other than the brain injury, the time till death signifies nothing in respect of the size of this injury and the strength of the violence causing it. In order to be able to set satisfactory boundaries, all cases where something other than the brain injury contributed to the fatal issue have been dealt with separately. Two of the groups of 'Causes of death' are, however, so closely bound up with the actual brain injury that they call for particular discussion. These are the groups 'Aspiration', and 'Pneumonia' (see p. 00). Both the aspiration and the pneumonia, which is of the bronchial type (aspiration pneumonia) are, of course, results of the unconsciousness set up by the brain injury. They differ, however, in their clinical course, and table 6 shows the remarkable difference in their times till death. The suffocating aspiration of blood or vomited contents of the stomach sets in shortly after the act of violence, while pneumonia takes longer to develop. In the former case even a fairly slight injury, which in itself would only have given a short unconsciousness and not threatened life, may prove fatal. In the latter cases it takes a more severe effect on the brain with accompanying lengthier unconsciousness, or at any rate lowering of consciousness. Looked at this way, the complicating pneumonia becomes more of a direct symptom of the gravity of

the brain injury than aspiration, which may be present at any brain injury whatsoever. In the following pages, the group 'Pneumonia' has been dealt with separately and, when necessary, added to the group 'Death from brain injury', whereas the group 'Aspiration' has at once been grouped with the other causes of death.

TABLE 17. *Group 'Blunt violence to free head. One system of deep injuries'. Type of fracture — Cause of death.*

Type of fracture	Brain only	Pneumonia	Other	Total
No direct fracture	5	5	5	15
Short fissure	1	3	3	7
Meridional fissure	33	8	20	61
Total (without depression)	39	16	28	83
Globus fractures	10		3	13
Sector fractures	8		4	12
Segment fractures	2		5	7
Total (with depression)	20		12	32
?	4	1	1	6
Total	63	17	41	121

Frequencies	Cases without depression	47.0±5.5	19.3±4.3	33.7±5.2
	Cases with depression	62.5±8.6	0±0	37.5±8.6
Differences between the groups		−15.5±10.2	19.3±4.3	3.8±10.0

The time till death can, it is true, be expected to give an insight into the clinical course of the different types of injury, but it is difficult to say *a priori* which injuries are to be regarded as the most serious — those that have a short time till death, or those with a long. We must once again be careful with conclusions drawn from an autopsy material. Any notion of the danger to life of the different injuries can only be got from a material of living persons. Brain injuries showing a short time till death can of course be regarded as serious, for we like to think that the more serious an injury is, the more immediately fatal it will be. On the other hand, a conceivable selection mechanism is that one type of injury is slight and only gives a few cases of death; but

these occur early in the course. Those persons sustaining an injury of this kind must, then, be thought of as recovering rapidly after the injurious effects, and the risk of death later on would thereby disappear. In contrast to this, that type of brain injury would be more serious, then, that shows an on an average longer time till death, for in this group the threatening effect on the brain would persist for a longer time.

When the different types of fracture are compared in this respect, we see statistically significant differences between the 'Depression fractures' on the one hand and the 'Injuries without depression' on the other. The sub-sections in these two main types do not, on the other hand, show any significant differences from one to the other. In accordance with this, it is not surprising that all cases where the cause of death was a complicating pneumonia are found among the 'Injuries without depression' (Tab. 17.). This difference is statistically significant. We are therefore justified in collocating the groups 'Death from brain injury' and 'Pneumonia' in the comparison between depression fractures and injuries without depression (Tab. 18.). Cases with complicating pneumonia constitute a systematic selection of the late cases of death within the group 'Death from brain injury', and this selection tries to wipe out the difference there is. (The comparison between cases with and without depression fracture in the group 'Death from brain injury' shows in the material presented here also a difference which is only statistically probable.)

If these two characters i. e. the size of the brain injury and the time till death discussed above are put together, no certain relation is obtained. These comparisons have been made in those groups of cases where there was only *one* brain injury, and this injury alone proved fatal. The groups are therefore small (injuries at the impact pole: 10 cases, meridional injuries: only 2 cases, and injuries at the opposite pole: 21 cases). In accordance with what has been said above, cases with complicating pneumonia have also been included. This deficient correlation is, of course, conceivably due to the smallness of the material, but it is also possible that we have here the real state of affairs. We could see herein support for the supposition that it is not the anatomically visible injuries that are the serious ones, functionally speaking. However, the selection mechanism discussed above may

tend to wipe out the possible relation, as a short time till death may indicate both serious and slight injury.

TABLE 18. *Group 'Blunt violence to free head. One system of deep injuries. Death from brain injury only or from complicating pneumonia'. Type of fracture — Time till death.*

Type of fracture	Cause of death	Time till death										Total
		0	Hours		Days						?	
			1–6	7–12	1	2	3	4	5	6–10		
No direct fracture	Brain only		2	1	1		1					5
	Pneumonia				2		2		1			5
	Total		2	1	3		3		1			10
Short fissure	Brain only				1							1
	Pneumonia						2			1		3
	Total				1		2			1		4
Meridional fissure	Brain only	5	8	3	10	2	3	1		1		33
	Pneumonia				2	1	2	1	1	1		8
	Total	5	8	3	12	3	5	2	1	2		41
Total (without depression)	Brain only	5	10	4	12	2	4	1		1		39
	Pneumonia				4	1	6	1	2	2		16
	Total	5	10	4	16	3	10	2	2	3		55
Globus fracture	Brain only	6	3								1	10
Sector fracture	Brain only	4	1		2		1					8
Segment fracture	Brain only	1			1							2
Total with depression	Brain only	11	4		3		1				1	20
?	Brain only	4										4
	Pneumonia				1							1

		Mean time till death	Differences
Cases without depression	Brain only	1.08 ± 0.25	-2.30 ± 0.60
	Pneumonia	3.38 ± 0.55	$+0.76 \pm 0.30$
	All cases	1.75 ± 0.27	$+1.43 \pm 0.32$
Cases with depression		0.32 ± 0.16	

The analysis thus made shows that the fracture type gives us a principle of division not only for the skull injuries but also for the course of the injury as a whole. It has previously been

established that blunt violence of different types (plane and shaped) gives different types of fractures, and that certain brain (and membrane) injuries are unconditionally bound up with certain fracture types: We see injuries at the impact pole only under depression fractures, and meridional injuries only along meridional fissures. It is now further established that the fracture type determines (is significantly correlated with) a feature so important clinically as the time till death, and that it to a certain extent determines the frequency and size of the brain injuries caused.

If, after a division of the different fracture types, we make a new comparison between the two main groups (cases where the brain injury alone proved fatal and cases where another injury or disease also contributed to or caused death), we find a strikingly good accordance between the two groups (Tab. 19). Although the majority of the groups are small, the frequency figures there agree remarkably well. Groups whose size allow of statistical treatment show differences which do not amount to twice the standard error. On this account it can be assumed that the previously established differences between the two main groups are due to the absence or under-representation of the fairly slight injuries in the group 'Death from brain injury'. We find, that is to say, that in groups with similar violence (= the same fracture form), the selection mechanism discussed by way of introduction can be ignored.

We are therefore justified in lumping the two groups together and studying the frequency of the four main types of brain injury in the different fracture groups (Tab. 20). Over and above the already known fact (for which we get statistically significant differences) that impact-pole injuries are only found in depression fractures and meridional injuries only along meridional fissures, the following is established: a) Meridional injuries to the brain are not observed along the meridional fractures included in the sector fractures; the difference between this type of fracture and the meridional fissures is statistically significant. b) The incidence of opposite-pole injuries to the brain is fundamentally different in the different groups; the greatest frequency is found in the meridional fissures, the frequency then falling in the groups 'Globus fractures', 'Cases without fracture' 'Other depression fractures', and is lowest in the group 'Short fissures'. There is a statistically probable difference between the groups 'Meridional

TABLE 19. *Group 'Blunt violence to free head. One system of deep injuries. Brain injuries and fractures known'* *.

Frequency (in %) of brain injuries — Type of fracture — Cause of death.

Type of fracture		Brain injured							
		at impact pole		meridionally		at opposite pole		in the interior	
		Brain only	Other	Brain only	Other	Brain only	Other	Brain only	Other
No direct fracture	Injuries	0	0	0	0	1	4	1	4
	Cases	5	9	5	9	5	9	5	9
	Frequ.	0	0	0	0	20	44	20	44
	Diff.	0		0		−24		−24	
Short fissure	Injuries	0	0	0	0	0	1	1	2
	Cases	1	5	1	5	1	5	1	5
	Frequ.	0	0	0	0	0	20	100	40
	Diff.	0		0		−20		60	
Meridional fissure	Injuries	0	0	10	12	31	21	4	4
	Cases	33	28	33	28	33	28	33	28
	Frequ.	0±0	0±0	30.3±8.0	42.9±9.4	93.9±4.2	75.0±8.2	12.1±5.7	14.3±6.6
	Diff.	0±0		−12.6±12.3		18.9±9.2		−2.2±8.7	
Globus fracture	Injuries	8	1	2	1	5	2	0	0
	Cases	10	3	10	3	10	3	10	3
	Frequ.	80	33	20	33	50	67	0	0
	Diff.	47		−13		−17		0	
Other depression fractures	Injuries	7	5	0	0	2	1	1	0
	Cases	8	9	8	9	8	9	8	9
	Frequ.	88	56	0	0	25	11	13	0
	Diff.	32		0		14		13	

* Case 127 (p. 74) not counted.

fissures' and 'Cases without fracture'; statistically significant differences are found between the group 'Meridional fissures' on the one hand and the groups 'Short fissures' and 'Other depression fractures' on the other. c) There are so few haemorrhages in the interior of the brain in the material that they cannot, with the division presented here, give any significant differences between the different groups. It is, however, worth noticing how numerous they are in the groups 'Cases without fracture' and 'Short fissures', and how few they are among the depression fractures. The only case observed in this group belongs, in addition, to the three showing injury at the opposite pole.

TABLE 20. *Group 'Blunt violence to free head. One system of deep injuries. Brain injuries and fractures known*'.*

Frequencies (in %) of brain injuries in the different fracture groups, and differences between the groups.

Type of fracture	Frequencies of brain injuries			
	at impact pole	meridionally	at opposite pole	in the interior
No direct fracture	0	0	36±13	36±13
Short fissure	0	0	17±15	50±20
Meridional fissure	0	36±6	85±5	13±4
Globus fracture	69±13	23±12	54±14	0
Other depression fractures	71±11	0	18±9	6±6
Differences between				
No direct fr. — Short fiss.	0	0	19±20	
» » » — Meridional fiss.	0	36±6	49±14	
» » » — Globus fr.	69±13	23±12	18±19	
» » » — Other depr. fr.	71±11	0	18±16	No
Short fiss. — Meridional fiss.	0	36±6	68±16	statistically
» » — Globus fr.	69±13	23±12	37±21	significant
» » — Other depr. fr.	71±11	0	1±17	differences
Meridional fiss. — Globus fr.	69±13	13±13	31±15	
» » — Other depr. fr.	71±11	36±6	67±10	
Globus fr. — Other depr. fr.	2±17	23±12	36±17	

* Case 127 (p. 74) not counted.

The relations found hitherto can be tabulated as follows:

Nature of violence	Fracture type	Brain injuries				Time till death
		at impact pole	along meridian	at opposite pole	in the interior	
Plane	None	Never	Never	Often	Often	Long
	Short fissures					
	Meridional fissures	Never	Often	Nearly always	Sometimes	
Plane or shaped	Globus fractures	Often	Often	Often	Not observed	
Shaped	Sector fractures	Nearly always	Not observed	Seldom	Seldom or never	Short
	Segment fractures	Nearly always	Never	Seldom		

The two main groups of injury thus established, namely injuries from plane violence and those from shaped violence, will now be investigated with regard to the localization of the site of violence on the surface of the skull. Theoretically, a difference in principle between the two groups can be anticipated: Let us, in the first place, consider the conditions in plane violence. The site of violence is then the point where the plane comes into contact with the curved surface of the skull. This must mean that even in plane violence dealt at random, the sites will come to collect on the more curved parts of the skull's surface. Added to this, in falls to or blows against a rather larger plane surface, the trunk will prevent there being any site of violence on the under part of the skull. It goes without saying that the skull base is in the first place directly protected, but the temporal regions will also be relatively protected in falls to one side by the shoulders taking the brunt of the impact. In cases where the rest of the body is hit first, its motion is changed and, if the head then strikes against the plane surface, the site of violence will be localized in a zone round the largest horizontal circumference of the skull. The skull's own form and its relation to the rest of the body will thus decide the localization of the plane violence.

As regards the shaped violence, it must on the other hand be that the more or less projecting edges or corners may encounter any spot whatsoever on the free surfaces of the skull.

A division of all the cases with plainly enough described surface injury that are included in the material previously dealt with is also in complete consonance with the theory. Plane violence is seen (Fig. 28 a and b.) most densely accumulated just round the greatest horizontal circumference of the vault, while it is clearly sparser over the crown and altogether missing in the almost plane anterior parts of the crown. It is densest in the occiput. The surface injuries from blunt violence, which reproduce the shape of the instrument inflicting them, are on the other hand found (Fig. 29 a and b.) more irregularly distributed over the vault. The noteworthy accumulation of shaped injuries in the forehead is explained by the fact that the forehead is especially exposed to collision injuries in traffic accidents.

Now, as shaped violence gives skull and brain injuries chiefly localized in immediate association with the impact pole, we can

at once get from fig. 29 an idea of the localization of appurtenant bone, membrane, and brain injuries.

Plain violence on the other hand gives chiefly indirect deep injuries, and a closer analysis of the relation with the site of violence is therefore warranted. Fig. 30 a and b gives the sites for the violence setting up injuries at the opposite pole. The schematic survey plainly shows the opposite-pole injuries to be localized within the diametrically opposite poles of the brain; it also shows their size. We find that violence in the occipital region has the highest frequency of opposite-pole injuries, and that the most extended and deepest are similarly got from violence to this region. A remarkable fact is that no case of violence to the crown has given injuries at the opposite pole. The cases are not many, it is true, but the frequency of opposite-pole injuries in violence to the greatest horizontal circumference is so high that a representative difference may well be assumed.

This state of affairs gives a simple physical explanation to the accumulation of opposite-pole injuries at the tips of the different lobes of the cerebrum (a fact observed earlier on, and confirmed by the present author): Plane violence accumulates round the most curved portions (occiput, tubera parietalia and frontalia); violence to the sinciput is rare, and even when it occurs does not give injuries at the opposite pole. The opposite-pole injuries are localized round the point of contact between the surface of the brain and a plane at right angles to the direction of the impact. The most curved parts of the brain's surface will therefore more frequently be the seat of opposite-pole injuries. These two factors co-operate, so that we get pairs of opposite points, showing a higher frequency of plane injuries than elsewhere (in the scalp at the impact pole, and in the brain at the opposite pole):

Occiput	—	The tips of the frontal and temporal lobes.
Forehead	—	The tips of the occipital lobes.
Tuber parietale sin.	—	Right temporal lobe's tip and outer side.
» » dex.	—	Left » » tip and outer side.

The violence giving injuries in the interior of the brain does not, on the other hand, show any predilection for any particular part of the skull's surface (Tab. 21.). This conflicts with the

statement that injuries in the interior of the brain are mainly set up by violence to the temples (Esser, 1933 b). The number of cases is too small to allow of any certain conclusions, however.

TABLE 21. *Group 'Blunt violence to free head. One system of deep injuries. Cases with brain injuries in the interior'. According to localization of the impact.*

The head struck	Number of cases
directly from behind	1
obliquely from behind	6
from the side	3
obliquely from in front	4
directly from in front	1
from above	1
?	1
Total	17

Violence giving extradural bleeding shows a plain accumulation in the vicinity of the fossa cranii, in which the haemorrhage spreads (Tab. 22.). There are exceptions, however, and there are in the material examples of long meridional fissures which by their terminal ramifications set up laceration of a meningeal artery.

TABLE 22. *Group 'Blunt violence to free head. One system of deep injuries. Cases with extradural haemorrhage'. According to localization of the impact and of the haemorrhage.*

The head struck	Extradural haemorrhage in the		
	fossa ant.	fossa med.	fossa post.
obliquely from behind on the other side		1	
directly from behind		1	1
obliquely from behind on the same side		2	
from the same side		6	
obliquely from in front			
directly from in front	1		
?		1	
Total	1	11	1

Although the composition of the anatomical material does not permit any exact statistical treatment, it has nevertheless been the author's wish to give the following tabular survey of it. The thing is that it may be of value to check whether the correlations now found come out in this material, too. It is true that there are a number of cases common to both groups (the previously dealt with 121 cases with *one* application of blunt violence to the free head and corresponding cases in the anatomical material), but these cases form no very great part even of the anatomical material (14 of 43). In addition, the anatomical investigation of appurtenant brains gave a picture with considerably greater wealth of detail than could be found in the medico-legal reports:

The group of specimens with injuries at the impact pole (Tab. 23.) provides nothing new.

TABLE 23. *Specimens with brain injury at the impact pole.*

Type of fracture	Number of cases	Cases which in addition show brain injury	
		meridionally	at the opposite pole
Globus fracture	3	3	2
Sector fracture	2	0	1
Total	5	3	3

The group of specimens with meridional injuries (Tab. 24.) are, as we already knew, only represented in the groups 'Meridional fissures' and 'Globus fractures'; these injuries are most frequently combined with opposite-pole injuries to the brain.

TABLE 24. *Specimens with brain injury meridionally.*

Type of fracture	Number of cases	Cases in addition showing brain injury		Magnitude and localization		
				Cerebrum		Cerebellum
		at impact pole	at opposite pole	Perivasc. haemorrh.	Laceration	
Meridional fissure	14		12	9	1	4
Globus fracture	6	4	4	5	1	
?	1		1			1
Total	21	4	17	14	2	5

The group of specimens with opposite-pole injuries is the largest, and allows of a division according to the anatomically different types (Tab. 25). A number of interesting indications can be got by collocating these different types with the person's age

TABLE 25. *Specimens with brain injury at the opposite pole.*

Type of fracture	Number of cases	Cases additionally showing brain injury		Magnitude and localization					
				In the cortex				In cortex and medulla	In the medulla
					Deep				
		at impact pole	meridionally	Surface	Limited	Extended little	Extended much		
No direct fracture	2								2
Meridional fissure	24		13	2	5	7	5	5	
Globus fracture	6	4	4		3	2		1	
Sector fracture	2	1	1	2					
?	1		1				1		
Total	35	5	19	4	8	9	6	6	2

at death and the time elapsing from the application of violence to death, even if the material is too small and too unsystematic to warrant any definite conclusions. We see, thus, that the particularly extensive injuries at the opposite pole are found primarily among young persons, while the deeper cortex and medulla injuries are usually found among old persons (Tab. 26.).

TABLE 26. *Specimens with brain injury at the opposite pole and with meridional fissure.*

Type of the opposite-pole injury — Age at death.

Type of injury			Age years								Total
			0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	
In the cortex	Superficial								2			2
	Deep	Limited			1		3	1				5
		Extend. little		1	1	2	1	1			1	7
		Extend. much		1	3			1				5
In cortex and medulla							2		2		1	5
Total				2	5	2	6	3	4		2	24

It may also be mentioned that there was a high age at death (71 and 85 years respectively) in both cases of focal cortex injury isolated from the actual injuries at the opposite pole, described in Section 2. This agrees with Schwarzacher's (1924) findings of 'traumatische Markblutung' mainly in old people. A division of this group (opposite-pole injuries in the anatomical material with simultaneous meridional fissure) shows that the cortex and medulla injuries have a longer time till death than the pure cortex injuries. The smallness of the material permits of no certain conclusions, however.

TABLE 27. *Specimens with injury to the interior of the brain.*

Type of fracture	Number of cases	Above tentorium	Below tentorium	Cases additionally showing brain injury		
				at impact pole	meridionally	at opposite pole
No direct fracture	1	1				
Short fissure	1	1				
Meridional fissure	7		7		3	7
Total	9	2	7		3	7

The group of specimens with injuries in the interior of the brain (Tab. 27.) falls into two groups: One (7 cases) shows meridional fissures and haemorrhages which are localized round the aqueductus Sylvii and under the anterior half of the fourth ventricle, i. e. of the type that Berner in particular described so fully. All cases in this group are combined with injuries at the opposite pole, and 3 of the 7 cases with meridional injuries as well. The second group (only 2 cases) shows deep haemorrhages in the cerebrum but not in the brain stem. In the one case the skull is whole, in the other it shows only a short fissure. The localization of violence on the surface of the skull does not show any systematic tendency in the anatomical material, either.

Guided by these, not statistically significant observations the author has regrouped as follows the statistical material (more exactly, the group with blunt violence to the free head):

The 28 cases of haemorrhage in the interior of the brain have been divided according to their localization into two groups (Tab.

TABLE 28. *Group 'Blunt violence to free head. Brain injury in the interior'.*

Type of fracture	Central injuries	Posterior injuries
No direct fracture	6	1
Short fissure	4	1
Other fractures	9	7
Total	19	9
Cause of death		
Brain injury only	8	7
Complicating pneumonia	9	
Other causes of death	2	2

		Time till death								Total	Mean, days.	Differences
		0	1–6	7–12	1	2	3	4	5			
Central injuries	Brain only	2	1		3		1	1		8	1.26±(0.49)	−1.07±0.67
	Pneumonia				4		4		1	9	2.33±(0.45)	1.17±0.50
	Total	2	1		7		5	1	1	17	1.83±0.36	1.74±0.37
Posterior injuries		3	3	1						7	0.086±(0.072)	

TABLE 29. *Group 'Blunt violence to free head. One system of deep injuries. Cases with meridional fissure'.*

*Magnitude of the brain injury at the opposite pole — Age at death.**

Magnitude of injury	Age (in years)								Total
	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	
No injury at opposite pole	2 ***		2	1	1	2			8
a 1 **			4					1	5
a 2			2	1	1				4
b 1	1 ****	1	2	2	3	2	1	1	13
b 2		2	4	1	5	2	2	2	18
c 1		1	1		1	1			4
c 2			1	2	2	2		1	8
Total	3	4	16	7	13	9	3	5	60

Correlation coefficient, $r = +0{,}23 \pm 0{,}12$.

* One case: Age unknown. ** For explanation see tab. 16.

*** Case 186 (p. 73). Case 188 (p. 72).

**** Case 18 (p. 74), doubtful.

TABLE 30. *Injuries to infants, 15 cases.*

a. *Age and sex.*

Age at death	Sex			Remarks
	Male	Female	?	
New-born	7[g]	3	1	See part b
Months 1				
2	1[i]			Murder. Blunt end of an axe
3	1[m]			Course of events unknown
4				
5				
6		1[e]		Murdered by mother, afterwards committing suicide. Lengthy instrument
7				
8		1[o]		Course of events unknown
Total	9	5	1	

b. *The new-born.*

Weight of the body	Number of cases	Course of events
2100—2500	5[g]	Precipitate delivery 1 { One application of blunt violence
2600—3000	3	Infanticide 10
3100—3500	2	Of these: Without confession 7[g]
3600—4100	1	With confession 3
Total	11	Of these: Case a: Several blows with a board
		Case d: Several blows against the floor
		Case f: Several blows with boards nailed together, the heads of the nails sticking out

28.): 1) 'Central injuries', situated above the tentorium cerebelli and 2) 'Posterior injuries', situated under the tentorium cerebelli. In this material, too, we see the central injuries tend to be more represented among the cases without fracture or with only short fissures, but there are no significant differences. On the other hand, there is a statistically significant difference between the times till death in the two groups — longer time in the group 'Central injuries', and shorter in 'Posterior injuries'. So that it is also not surprising that the cases with pneumonia as cause of

c. *Surface injuries:* Non-shaped wounds and stampings (P) 3^{bjk}
Shaped wounds and stampings (S) 3^{efi}
Bleeding under uninjured skin (?) 9^{g}

d. *Fractures:* One fissure or one system of fissures (M) 6
Two systems of shaped fractures with depression (D) 1^{i}
One or more fracture systems of uncertain type (?) 8^{g}

e. *Connexions:*

Surface injury	Type of fracture			Total
	M	D	?	
P	1^{b}		2	3
S	1^{e}	1^{i}	1^{f}	3
?	4		5^{g}	9
Total	6	1	8	15

Type of fracture	Bleeding between the membranes		Brain injury		Total
	+	−	+	−	
M	3	3		6	6
D	1^{i}		1^{i}		1
?	8^{g}		1^{g}	7	8
Total	12	3	2	13	15

Obs.! The 15 cases are signalized by letters a—o, and cases of interest are indicated in the tables by their letters.

death are only to be found in the 'Central injuries' group. This difference, too, is statistically significant.

The relation between the size of the opposite-pole injury and the time till death has previously been investigated in that group of the statistical material showing *one* application of blunt violence to the free head, where this opposite-pole injury was the only visible brain injury and where the latter, alone or in combination with pneumonia, was the cause of death. No relation was found. If we now in the 61 cases showing meridional fissure and *one* blunt violence to the free head collocate the age at death and the size of the opposite-pole injury (Tab. 29.) we get a positive correlation which is statistically not significant, however. It is noteworthy that two of the three cases in the youngest group have no brain

injury at the opposite pole at all, although the site of violence in both cases was in the occipital region, and we should therefore expect such an injury. (The other cases *with* meridional fissure but *without* injury at the opposite pole can as a rule be explained by the fact that violence was applied to the sinciput or the forehead, and that in the latter case there was also splintering of the orbital roofs. There then remain only two cases (with violence in the occipital region), and in both these the fracture descriptions are summary: It is possible that one case concerns a globus fracture and the other two short fissures. In the latter case there are also haemorrhages in the interior of the brain above the tentorium.)

These findings have prompted the author also to take up for treatment those cases in the archives of the medico-legal institution which show blunt violence to the head of infants. Cases without fracture have been ruled out here, however. Table 30 shows how the material is composed. It is seen to be impossible to apply the same detailed principles of division here as when dealing with the injuries of older persons, and reliable data as to the course of events are missing in a large number of cases. All the same, we can with certainty sort out six cases, where we have a uniform fracture system of meridional type (cf. Panning 1940). Neither in these six cases nor in any of the others where the type of fracture is less clear do we find cerebral injury at the opposite pole. Injuries to the brain are found only in two cases: In one it is a deep, direct injury under a distinctly described depression fracture. In the other case, the brain shows at some spots in the sincipital region small groups of haemorrhages under a large fracture system. On the other hand, most of the cases exhibit subdural or subarachnoidal haemorrhage, and one of them shows copious extradural bleeding. These haemorrhages are obviously the factor threatening life in blunt violence to the heads of infants.

It is worthy of mention that Kocher, to support his theory ('die akute Hirnpressung'), advanced the 'fact' that, on account of their 'very elastic' skulls, children have especially large cerebral injuries ('intensive locale Zerstörungen in Form von localer Quetschung und umschriebener Contrecoupquetschung', 1901, p. 302). Futhermore, he thought that, as the skull gets more and more rigid (with increasing age), it takes up more and more

of the kinetic energy of the impact, and that in the conjectured boundary case 'bei absolut starrem Schädel' the impact would not be transmitted to the brain at all. He advanced no casuistics to prove this statement. As was described above, the present author's material shows the state of affairs to be precisely the reverse. (It has already been shown in Chapter II that Kocher's theory is physically untenable.)

b. The relation between the properties of the instrument inflicting injury and the inflicted injuries.

In the foregoing section the correlation has been worked out between the different injuries to the different parts of the skull and the brain. As far as the instrument's properties are concerned, we were only concerned in this part with the form of the striking surface ('plane' and 'shaped' respectively). It was found that this division was of fundamental importance for the type of the resulting injuries. The aim of the following investigation is to try and discover whether an exacter analysis and a more detailed division according to the different properties of the instrument can help to explain the differences between the injuries caused to skull and brain.

For this analysis the whole of the statistical material has been used. On this account analysis has been continued of the cases which are not included in the group treated statistically earlier on — namely the cases with two or more applications of violence which might cause deep injuries, as also the cases where it was not certain whether violence had been applied to a free or a supported head. Here the correlations found in the previous subsection have been used:

In the first place the cases have been divided up according to the number of fracture systems, and for each system there was no difficulty in pointing to a definite surface injury as the site of violence. After this, each application of violence of this kind was re-tested, to see whether possible injuries to meninges and brain can be explained by the violence in question. We find in the first place a number of cases where all deep injuries can be explained by a single application of violence (in all cases *one* fracture system). After this there come a smaller number of cases each showing signs of two applications of violence with deep

injuries (in 7 cases two fracture systems per case, in one case one fracture system and an opposite-pole injury in violence without fracture). None of the systems of injury mentioned hitherto conflict with previously found rules.

Difficulties are revealed on the other hand in those groups of cases with haemorrhages in the interior of the brain or in the membranes without any certain source. In the former group there are 7 cases with only one fracture system, and the act of violence giving this system has also been assumed to give the injury in the interior of the brain. In none of the cases was this assumption irreconcilable with previously found correlations. Further there are 2 cases each with two fracture systems: In the one case the systems were of the same type, and it does not therefore matter from a statistical viewpoint which of them is made responsible for the injury in the interior of the brain. In the other case there is a meridional fissure and a segment fracture, and the interior injury has therefore been referred to the violence giving the fissure. In the latter group (only meningeal haemorrhages), the cases with fracture give no trouble. There then remain two cases from each of the groups without fracture. In two of these cases the instrument is not known, so that nearer analysis is unnecessary. In the third, both the surface injuries (haemorrhage under intact epidermis) are in the forehand, and probably inflicted at the same time (passenger in a motor smash). In the fourth case, we can choose between a shaped stamping of a murderous instrument and a small haemorrhage beneath uninjured skin. As the man was knocked senseless by the blow with the instrument, this last is considered the cause of the deep injury.

Among the cases where it is not clear whether violence was applied to the free or the supported head, it is now possible to sort out a number of injury systems which must be due to violence to the free head, since they also include injuries to the brain at the opposite-pole. Of the two cases in this group that do not display fracture, one of them is entirely obscure as to origin. The other case shows a small cortex injury, which, as the skull is uninjured, must be an opposite-pole injury. Violence must therefore have encountered the free head, and it can definitely be said which of the two surface injuries corresponds to this violence.

Table 31 gives the correlation between the number of cases,

TABLE 31. *Connexion between cases and impacts in the statistical material.*

a. *Previous division of the material.*

0 Cases with diseases of the brain or without known violence			5
1 and 2. Blunt violence			
Free head	One system of deep injuries		121
	Two or more systems of deep injuries possible		55
Free? supported head			13
Supported head			$9\,^{1}/_{3}$*
3 Gunshot			
Shot injuries		2	
Bullet injuries		8	10
4 Edged violence			
Case with 1 fracture system		3	
» » 2 » systems		2	
» » 3 » »		$^{2}/_{3}$*	$5\,^{2}/_{3}$
		Total	219

* Case 204 (p. 71).

b. *Previous and new division of the group 'Blunt violence'.*

Previous division	Free head. One system of deep injuries	Free head. Two or more systems of deep injuries possible	Free? supported head		Supported head	Total
New division	Free head			Free? supported head	Supported head	
Cases without fracture	15	4	1	1		21
Cases with 1 fracture system	100^{100}	35^{35}	1^{1}	4^{4}	8^{8}	148^{148}
Cases with 2 fracture systems		10^{20}	$^{1}/_{2}{}^{1}$	$2\,^{1}/_{2}{}^{5}$		13^{26}
Cases with 3 or more fracture systems			$^{1}/_{3}{}^{1}$	$^{2}/_{3}{}^{2}$	$1\,^{1}/_{3}{}^{3}$	$2\,^{1}/_{3}{}^{9}$
Cases with unknown type of fracture	6	6		2		14
Total	121^{100}	55^{55}	$2\,^{5}/_{6}{}^{3}$	$10\,^{1}/_{6}{}^{11}$	$9\,^{1}/_{3}{}^{14}$	$198\,^{1}/_{3}{}^{183}$

Obs.! Small figures (exponents) indicate number of impacts treated in the following tables.

previously relegated to different groups, and the number of impacts (with appurtenant systems of injuries), which will be dealt with in the following paragraphs. We rule out of this treatment the five cases belonging to group 0 (pathologically changed brains and cases without known violence respectively), as also 14 cases with unclear fracture form. Table 32 gives the first survey over the instruments inflicting injury included in the material, and the cases and impacts are divided up into the now corrected groups 'Free', 'Free ? supported', and 'Supported'. With regard to the gunshot injuries and those from edged violence, there is nothing more to add to what has been described in Section 2 of this chapter. As regards the injuries from blunt violence it is found that in the remaining group 'Free ? supported' there is only shaped violence which gave sector or segment fractures (without injuries at the opposite pole). The explanation of this is that it does not affect violence of this kind whether the head is supported or not, for similar injuries are found both in the group 'Violence to the free head', and in the group 'Violence to the supported head'. Guided by the probable course of events, these cases have been lumped together with the group 'Violence to the free head'. Further, we can now do without the division into the groups 'Plane violence', 'Shaped violence', and 'Plane ? shaped violence', since regard has even so been paid to the form of the instrument inflicting injury, *and* in more detail, moreover.

As has already been mentioned, the group 'Violence to the supported head' also contains cases with large fracture systems, not described in more detail, as a result of being run over.

Table 33 gives a survey of the whole material, and table 34 a further division of the very heterogeneous group of motor-car collision injuries in table 33. The tables give in the first place the correlation between the properties of the instrument and the fracture form imparted. In addition the number of cases with injuries at the impact pole, in the interior of the brain, and at the opposite pole is given in each group.

A mere glance at the tables shows that a division of this kind is of great importance for understanding the genesis of the injuries. It would naturally have been of advantage to have gone into still more detail, but both the smallness of the material and the fact that no very great attention has been paid to these viewpoints in

TABLE 32. *Instruments - Number of impacts.*

a. *Blunt violence to free head.*

Instrument	Cases without fracture				Impacts with fractures			
	Plane violence	Shaped violence	?	Total	Plane violence	Shaped violence	?	Total
The ground (floor)	8			8	78	3	1	82
Clamped object					4	3		7
Locomotive						2		2
Car	5	1 *		6	15	21		36
Blunt end of axe					1	1		2
Hammer						1		1
Other free object		1 **		1		3	2	5
Part of (human) body					1	1		2
?				5				21
Total				20				158

* Case 127 (p. 74). ** Case 163 (p. 75).

b. *Blunt violence to free ? supported head.*

Instrument	Type of fracture		Total
	Sector fracture	Segment fracture	
Edge of a car	1		1
Blunt end of axe	1	4	5
?			5
Total			11

d. *Edged violence.*

Gash with an axe	9
Total	9

c. *Blunt violence to supported head.*

Instruments	Type of fracture				Total
	Meridional fissure	Sector fracture	Segment fracture	Extensive, not specified, fractures	
Running over by car { on road				5	5
Running over by car { on clayey field		1			1
Crushing between car and ground	1				1
Blunt end of axe — ground			1		1
Hammer — cushion *	1	4			5
?					1
Total					14

* Case 187.

TABLE 33. *Group 'Blunt violence to (actually or probably) free head'.*

Instrument — Injury.

Instrument	Cases without fracture	Impacts with known type of fracture									
		Short fissure	Meridional fissure	Globus fracture	Sector fracture	Segment fracture	Total	State of brain reported			
								Number of impacts	Brain injured		
									at imp. pole	in the interior	at opp. pole
The ground	8	6	66	9	1		82	82	7	10	65
Clamped object			2	2	2	1	7	7	3	2	4
Locomotive					1	1*	2	2	2		
Car	6	4	11	6	13^{2}	3	37	35	11	6	15
Blunt end of axe			1		2	4	7	7	3		2
Hammer						1	1	1	1		
Other free object	1^{β}		2^{γ}	1^{δ}	1^{ε}	1^{ζ}	5	5	2		3
Part of body		1^{η}				1^{ϑ}	2	2			
?	6	6^{1}	13^{2}	2^{1}	1	4	26	22	3	3	12
Total	21	17	95	20	21	16	169				
State of brain reported	21	16	93	19	19	16		163			
Brain injured: at impact pole	1^{α}			11	13	8			32		
Brain injured: in the interior	7	5	13	1	2					21	
Brain injured: at opposite pole	8	3	81	11	4	2					101

Obs.! Exponents indicate number of impacts, where state of brain is not reported,

α Case 127 (p. 74).

β Case 163 (p. 75).

γ Wooden club. Flat-iron, plane surface.

δ Pulled-up iron paling

ε Falling level-crossing beam.

ζ Flat-iron, corner.

η Knee.

ϑ Knuckle. Case 119 (p. 71).

* Case 133 (p. 71), actually belongs to Group 'Sector fractures'.

TABLE 34. *Group 'Blunt violence to (actually or probably) free head Instrument car'.*

Colliding part of the car — Injury.

Colliding part of the car	Cases without fracture	Impacts with known type of fracture									
		Short fissure	Meridional fissure	Globus fracture	Sector fracture	Segment fracture	Total	State of brain reported			
								Number of impacts	Brain injured		
									at imp. pole	in the interior	at opp. pole
Pane of glass	5		3	1			4	4	1	1	3
Body		1	2		2		5	5	1	1	2
Metal framework			1	3	2[1]		6	5	2		1
Protruding metal part			1	1	4[1]	3	9	8	3	1	3
Edge of lorry platform	1*				1		1	1	1		
?		3	4	1	4		12	12	3	3	6
Total	6	4	11	6	13	3	37				
State of brain reported	6	4	11	6	11	3		35			
Brain injured: at impact pole	1*			2	7	2			11		
Brain injured: in the interior'	2	3	2		1					6	
Brain injured: at qpposite pole	4	1	10	2	2						15

Obs.! Exponents indicate number of impacts, where state of brain is not reported.

* Case 127 (p. 74).

the medico-legal reports have proved obstacles here. All the same, several certain or indicated correlations can be gathered from the two tables:

Among falls to the ground, the meridional fissures dominate; there are no segment fractures and only one sector fracture. We have reason to doubt the conclusion in a solitary case like this, but the descriptions in the report do not warrant any certain fresh appraisal. Of the two remaining cases with shaped surface injury from falls to the ground (against clearly described, pro-

jecting edge), one shows a system of meridional fissures (Fig. 10 b.) and the other a globus fracture.

Clamped objects (e. g. trees, telegraph posts, palings of wood or metal) seem to give more extended fracture systems than free objects (e. g. blunt end of an axe, hammer, and other weapons). In blows with a hammer (and also blunt end of an axe) the limited depression fractures (segment fractures) predominate. The detailed division of motor smash injuries shows a similar tendency: The plane parts give mainly meridional fissures; the more shaped mainly sector fractures; very much projected metal parts also give segment fractures. A remarkable thing is that of six collision injuries without fracture, five of them were caused by blows against a pane of glass. (The sixth case is Case No. 127, mentioned several times previously, and no doubt incompletely registered.)

As regards brain injuries, we naturally find in the thus expanded material the same correlation with the fracture form as described before. In the different groups of cases with different instruments, we similarly get distinct differences in the frequency of the different cerebral injuries. All the same, the differences do not seem to be as pronounced as in the fracture groups, and may well be explained via the separate fracture types in the different groups. It is nevertheless remarkable that the present author's material confirms Harbitz's observation that haemorrhages in the interior of the brain are not seen after blows from a weapon.

In two cases a fatal injury has been caused by part of another person's body hitting the skull. In both cases it was a question of small fractures in thin squamae temporales with extradural bleeding. Injuries to the brain were not seen in either of the cases.

Chapter IV.

The theory of the skull and brain injuries.

1. Short survey of the theory of elasticity and of the elastic impact.

If one elastic body is acted upon by another a distortion occurs necessitating the performance of work, which is stored up in the distorted body as elastic strain-energy, A_ε, whose magnitude (as always) is determined by the applied force, P, multiplied by the displacement in the direction of the force, x. Thus the elementary work is

$$dA_\varepsilon = P \cdot dx \tag{1}$$

The body resists the force, and a reaction is set up equal to the applied force. The greater the strain, the greater will this resistance be, and, therefore, the greater the applied force — i. e. the force P will be a function of the displacement x:

$$P = f(x) \tag{2}$$

The elastic strain-energy must therefore be expressed as an integral

$$A_\varepsilon = \int_0^x f(x)\, dx \tag{3}$$

If a rod is acted upon longitudinally, there is a distortion (extension or compression) whose magnitude is expressed by this extension, x (regarding a compression as a negative extension only). The corresponding increase or decrease in the thickness of the rod does not affect the following deductions. If this extension is expressed in relation to the original length of the rod, l, we get the fractional extension, $\varepsilon = \frac{x}{l}$. The force P required

to produce a certain fractional extension in a rod of a given material is directly proportionate to the cross-sectional area of the rod, a. The resistance of the rod to external distorting forces is thus also directly proportionate to its cross-sectional area. The ratio of the resistance, P, to the cross-sectional area, a, expresses the stress, S, prevailing in the rod:

$$S = \frac{P}{a} \tag{4}$$

The theory of elasticity builds on the assumption that the stress, S (and thereby the force, P) is directly proportionate to the resultant fractional distortion:

$$S = k \cdot \varepsilon.$$

This assumption agrees well with observations for small distortions. The limit where this equation no longer holds in practice is called the limit of proportionality. The constant, k, has different values for different materials. It is called the modulus of elasticity, E, and by definition is the stress required to produce unit fractional extension.

The function given above, $P = f(x)$, can now be written

$$P = \frac{E \cdot a}{l} \cdot x \tag{5}$$

Hence the elastic strain-energy according to Equation 3:

$$A_\varepsilon = \frac{E \cdot a}{l} \cdot \frac{x^2}{2} \tag{6}$$

In the theory of elasticity it is further assumed that, when the external force is withdrawn, the elastic body completely resumes its original form — that is to say that potential (elastic strain-) energy acquired through the distortion is entirely reconverted to kinetic energy. This assumption also agrees well with experiment when small distortions are concerned. The limit beyond which a body cannot be distorted if it is to resume its original form is called the elastic limit.

The sequence of events when bodies collide is explained by applying the laws of elasticity. The theory of elastic impact has been developed by Saint-Venant (1867), and will be briefly described here.

When bodies collide, the surfaces of contact assume at the moment of collision a common velocity, which is imparted in infinitely short time to the adjacent, infinitely thin layers. This velocity corresponds to infinitely great acceleration and retardation respectively of infinitely small masses under the influence of a finite force, P, which in the distorted layers sets up the stress $\frac{P}{a}$ (a = the cross section). This stress acts equally in both directions, and immediately acts on the infinitely thin layers on either side, imparting to their infinitely small masses infinitely great acceleration and retardation respectively. The finite force which is thus continually required to accelerate or retard layer after layer maintains the strain in the inner (= facing the surfaces of contact) parts of the body. The whole process will have the aspect of a pressure wave transmitted in both directions from the surface of contact. Its velocity is a natural constant characteristic for the material concerned. It is called the velocity of sound, after the most important of such wave effects.

The effect is readily determined when rods receive impacts in the axial direction (Fig. 31.). Here the pressure wave is merely a plane, longitudinal wave, involving further equal masses in equal periods of time. Each fresh, infinitely thin layer undergoes the same increase (decrease) of velocity, and is compressed to the degree ε ($= \frac{\lambda}{l}$, fractional extension). The corresponding stress is $\frac{P}{a}$. The compressed layer lying behind can therefore move forwards with the constant velocity, $v_s = \frac{x}{t}$, while the pressure wave advances with the velocity of sound, $c = \frac{l}{t}$.

The force, P, which acts in the surface of contact (the impact force) thus both compresses and accelerates the rod in a section whose length is equal to the velocity of sound multiplied by the time. The velocity of sound may be calculated from these two effects of the force:

After the time t

Density of the material	ϱ
Mass of the compressed part	$\varrho \cdot a \cdot ct$
Velocity of the compressed part	v_s
Acceleration of the compressed part	$\frac{v_s}{t}$
Longitudinal distortion of the compressed part	$x = v_s \cdot t$
Fractional distortion of the compressed part	$\frac{x}{ct} = \frac{v_s}{c}$

$$P = \varrho \cdot a \cdot ct \cdot \frac{v_s}{t} = E \cdot a \frac{v_s}{c}$$

$$c^2 = \frac{E}{\varrho} \tag{7}$$

Since the same force (during the same time) causes both acceleration and compression, it is immediately plain that the impulse to both will be the same.

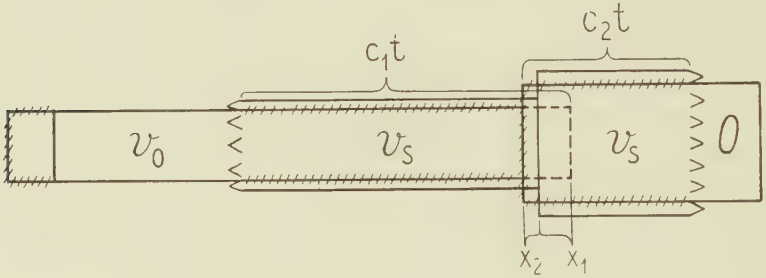


Fig. 31. Axial impact of rods.
Crossed lines = Moment of collision.
Straight lines = After arbitrary time, t, before either wave has reached the outher (free) end of the rod.
Row of arrowheads = Wave front.
Dotted lines = Inner end of the striking rod after time t, if no impact had taken place.

When two elastic rods collide axially, the same process is set up on either side, and the magnitude of the resulting accelerations and compressions will depend on the elastic properties of the rods:

Properties:	Rod I	Rod II
Velocity before impact	v_0	0 cm/sec
Velocity of sound	c_1	c_2 cm/sec
Density	ϱ_1	ϱ_2 g/cm^3
Cross section	a_1	a_2 cm^2

Properties:	Rod I	Rod II
Length	l_1	l_2 cm
Let $c \cdot \varrho \cdot a$ be	N_1	N_2 g/sec *
and $\frac{l}{c}$ be	L_1	L_2 sec *
The mass will then be	$N_1 \cdot L_1$	$N_2 \cdot L_2$ g
Let the common velocity of the compressed parts be		v_s cm/sec
and the longitudinal distortions	x_1	x_2 cm

No external forces act on the system, so that its centre of mass must have constant velocity. It follows that the momentum $(m \cdot v)$ is constant.

Momentum in the compressed parts of rod	Before the impact	After the time t
	I. $\varrho_1 \cdot a_1 \cdot c_1 t \cdot v_0$	$\varrho_1 \cdot a_1 \cdot c_1 t \cdot v_s$
	II. 0	$\varrho_2 \cdot a_2 \cdot c_2 t \cdot v_s$

whence

$$\left.\begin{aligned} v_s &= v_0 \cdot \frac{\varrho_1 \cdot a_1 \cdot c_1}{\varrho_1 \cdot a_1 \cdot c_1 + \varrho_2 \cdot a_2 \cdot c_2} = v_0 \cdot \frac{N_1}{N_1 + N_2} \text{ cm/sec} \\ \text{and} \\ v_0 - v_s &= \qquad\qquad = v_0 \cdot \frac{N_2}{N_1 + N_2} \text{ cm/sec} \end{aligned}\right\} \quad (8)$$

Impulse = Force × time = Change of momentum.

Hence it follows that

$$\text{the force of impact, } P = \frac{\text{Change of momentum (in each rod)}}{\text{Time}}$$

Thus

$$P = v_0 \cdot \frac{N_1 \cdot N_2}{N_1 + N_2} \text{ dyn} \quad (9)$$

We thus find that the impact force when rods impinge axially is independent of time as long as the same wave is in progress.

During the impact, the energy must also be constant, as the following table shows:

---

* The quantity N will hereafter be called the oscillating mass and has the dimension mass/time. The quantity L is the half period of oscillation of the body.

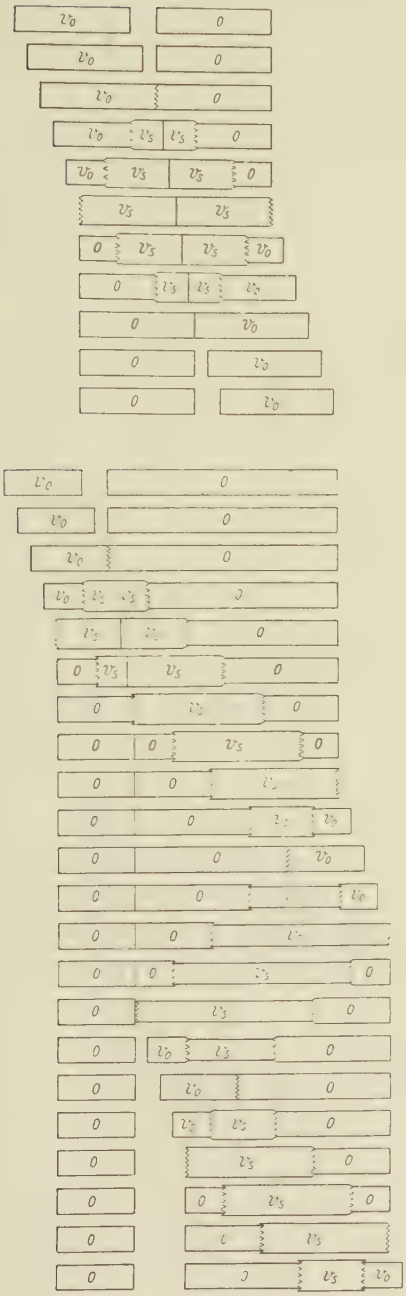
		Before impact Only kinetic energy	After time t	
			Kinetic energy	Elastic strain-energy
Energy in distorted parts of rod	I	$N_1 \cdot t \cdot \frac{v_0^2}{2}$	$\frac{N_1^3}{(N_1+N_2)^2} \cdot t \cdot \frac{v_0^2}{2}$ (10)	$\frac{N_1 \cdot N_2^2}{(N_1+N_2)^2} \cdot t \cdot \frac{v_0^2}{2}$ (11)
	II	0	$\frac{N_1^2 \cdot N_2}{(N_1+N_2)^2} \cdot t \cdot \frac{v_0^2}{2}$ (12)	$\frac{N_1^2 \cdot N_2}{(N_1+N_2)^2} \cdot t \cdot \frac{v_0^2}{2}$ (13)

When a pressure wave reaches the free end of a rod, the course is changed, as the end layer encounters no resistance but seeks to disappear into space. It is, however, retarded by its cohesion to the penultimate layer, and emits a decompression wave which moves inwards with the velocity of sound towards the surface of contact, successively neutralizing the compression. This imparts to the decompressed layers an increase (decrease) of velocity corresponding to the momentum transferred in the surface of contact. Thus the force of impact is not changed when the wave is reflected from the free end. The increase or decrease of the kinetic energy proportional to the square of the velocity is met by interconversion of elastic strain-energy and kinetic energy.

If the cohesion in the material is insufficient, fragments are torn away from the free end; examples of this can be drawn from practical experience. It is this phenomenon that Lenggenhager has employed to explain the genesis of contre-coup injuries (in cases without fracture of the skull).

When a decompression wave in a rod returns to the surface of contact, the inner end acquires the velocity of the decompressed portion. If this is *greater* than the velocity of approach the rod is jerked away and the impact ceases; at the same time a decompression wave is set up from the inner end of the other rod. If, on the other hand, the velocity of the decompressed portion is *less* than the velocity of approach, there is no room for a complete decompression of the other rod, and a new impact process is set up with a velocity of approach equal to the difference between the first velocity of approach and that of the decompressed rod. Different impact processes develop in accordance with the elastic properties of the rods (Fig. 32 a—c.).

Fig. 32. *Axial impact of rods. Different cases.*



a. Both rods have the same oscillating mass and period of oscillation.

Velocity of approach	v_0
Oscillating mass of each rod	N
Half period of oscillation of each rod	L
Velocity of compressed parts	$v_s=\frac{v_0}{2}$
Impact force	$P=N\cdot\frac{v_0}{2}$
Time of impact	$2L$
Transferred energy	$N\cdot L\cdot\frac{v_0^2}{2}$
Velocity of separation	v_0

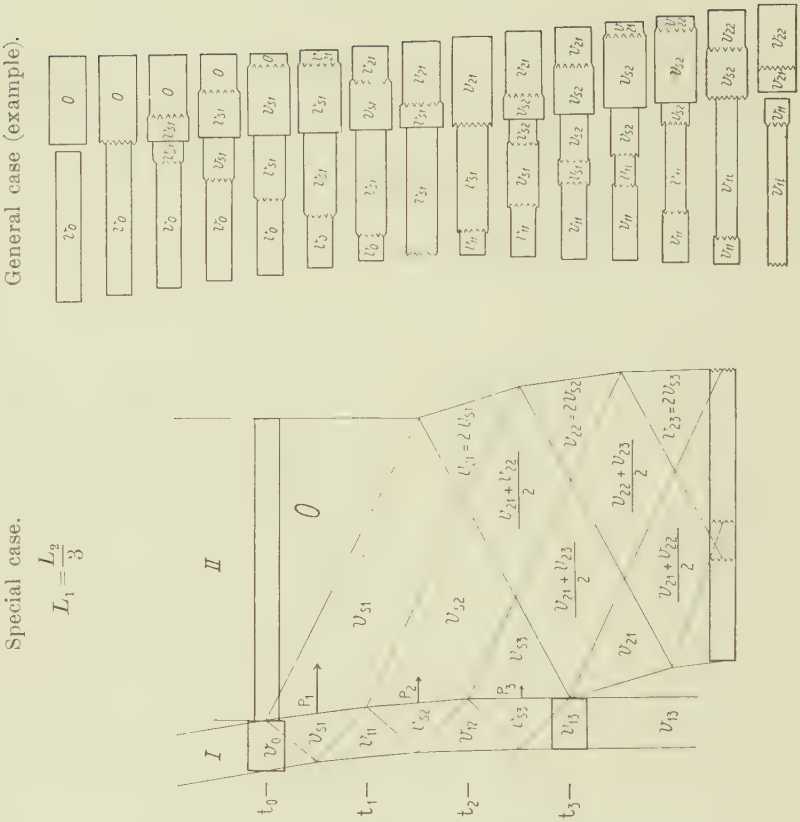
No remaining elastic strain-energy after the impact. In principle, the same course of impact in all cases of equal period of oscillation.

b. The rods have the same oscillating mass, but different periods of oscillation.

	Rod I	Common	Rod II
Velocity of approach		v_0	
Oscillating mass	N	$=$	N
Half period of oscillation	L_1	$<$	L_2
Velocity of compressed and extended parts respectively		$v_s=\frac{v_0}{2}$	
Impact force		$P=N\cdot\frac{v_0}{2}$	
Time of impact		$2L_1$	
Transferred energy		$NL_1\cdot\frac{v_0^2}{2}$	
Velocity of separation		$v_0\cdot\frac{L_1}{L_2}$	
Remaining elastic strain-energy after the impact	0		$+$

In principle, the same course of impact when the rod with *shorter* period of oscillation also has the *lesser* oscillating mass.

c. The rod with the *shorter* period of oscillation has the *greater* oscillating mass.



Ramsauer (1909) tested the theory of elastic impact by experiment. With suitable devices he was able to observe waves of compression, decompression, and extension, and checked the velocities in the two colliding rods before and after the impact. The experimental results are in complete agreement with the theory.

2. Application to the case 'Hollow sphere filled with fluid', theoretically and experimentally.

Now, when applying this theory to violence to the skull and brain, it is necessary to have an idea of the physical properties of these parts of the body. Calculations can only be carried out on models which, from a physical viewpoint, are more clearly

Moment or period of time	Rod I Velocites etc.	Common properties			Rod II Velocities etc.
		Velocities of compressed parts	Velocities of approach	Impact forces	
t_0	v_0		v_0		0
	Decrease of velocity,				
t_0-t_1	$v_{d1}=v_0-v_{s1}=v_0\cdot\frac{N_2}{N_1+N_2}$	$v_{s1}=v_0\cdot\frac{N_1}{N_1+N_2}$		$P_1=v_0\cdot\frac{N_1N_2}{N_1+N_2}$	
t_1	$v_{11}=v_0-2v_{d1}=v_0\cdot\frac{N_1-N_2}{N_1+N_2}$		$v_{01}=v_{11}$		On decompression the inner end takes back the velocity 0.
t_1-t_2	$v_{d2}=v_{01}-v_{s2}$	$v_{s2}=v_0\cdot\frac{N_1}{N_1+N_2}\cdot\frac{N_1-N_2}{N_1+N_2}$		$P_2=v_0\cdot\frac{N_1N_2}{N_1+N_2}\cdot\frac{N_1-N_2}{N_1+N_2}$	
t_2	$v_{12}=v_0\cdot\left(\frac{N_1-N_2}{N_1+N_2}\right)^2$		$v_{02}=v_{12}$		
t_2-t_3	$v_{d3}=v_{02}-v_{s3}$	$v_{s3}=v_0\cdot\frac{N_1}{N_1+N_2}\cdot\left(\frac{N_1-N_2}{N_1+N_2}\right)^2$		$P_3=v_0\cdot\frac{N_1N_2}{N_1+N_2}\cdot\left(\frac{N_1-N_2}{N_1+N_2}\right)^2$	
t_3	$v_{13}=v_0\cdot\left(\frac{N_1-N_2}{N_1+N_2}\right)^3$	Impact ceases.			$v_{21}>v_{13}$
		Time of impact $2L_2$			
		Transferred energy $N_1L_1\cdot\frac{v_0^2}{2}\left[1-\left(\frac{N_1-N_2}{N_1+N_2}\right)^{2\cdot3}\right]$			
	0 *	Remaining elastic strain-energy after the impact			+

* In the general case + (see fig.).

defined. It is desirable that these models correspond as nearly as possible to skull and brain.

The parts of the body in question consist of a bone capsule with a soft covering and a soft content.

The bone capsule consists of a stiff, elastic substance. The elastic properties of the bone tissue were studied by Rauber (1876), who calculated the elasticity modulus in different bones and at different ages. All that need be said of these results here is that the modulus of elasticity on the whole increases with age. The bone capsule has the form of an irregular ellipsoid, but should normally be comparable with a hollow sphere. Its thickness varies greatly in different parts of the skull, but the variations are chiefly in the part not directly exposed to external violence. Such violence is, as has already been shown, inflicted over the vault and down the occiput, and in these areas the bony wall is comparatively homogeneous in thickness and structure.

The outer soft parts (the evenly thick scalp) are also homogeneous over these parts of the skull. Any influence they have on the injuring process must therefore be the same everywhere. No account of such an influence is taken in the following pages, however.

The dura, which lines the inside of the skull evenly, will similarly be disregarded in the following pages.

The thin pia and arachnoid are, as we know, surrounded by fluid and can hardly be of any importance for the injuring process.

The brain itself is enclosed in the same fluid. Although common sense tells us its consistency is so soft that it must behave most like a fluid within its solid covering, its behaviour has been much discussed. Certain observations, that is to say (i. e. the occurrance of limited injuries at the opposite pole, injuries in the interior of the brain in the direction of the impact), have prompted certain authors (Kocher, Genewein, Reuter, Kalbfleisch, and others) to regard the brain as a solid body. In Chapter II these views have been discussed and countered.

In the following pages the contents of the skull will be regarded — from a physical point of view — as principally fluid, and the physical deductions build on this assumption. It will be an indirect proof of its accuracy if the brain injuries can subsequently be satisfactorily explained with the help of these deductions.

From an anatomical viewpoint, the brain is, of course, not fluid; the different parts each have their definite place. The brain injuries inflicted show, therefore, by their localization the site of the injurious physical states arising as a result of the violence.

Before passing on to discuss the impact process in a hollow sphere, we shall consider the conditions in a solid, elastic sphere. In this case the impact falls at a *point* of contact, where the stress becomes momentarily infinite, so that a distortion producing a *surface* of contact is set up. This surface is relatively small, however, and can be treated as a point from which the pressure wave emanates. The wave is propagated with the same velocity in all directions, so that the wave front is spherical, and the compression (and the compressive stress) decreases with the square of the distance. For the present no regard is paid to the shearing stresses. The outermost part of the spherical (segment-shaped) wave front is continually reaching new rings of the sphere's free surface. The component of the wave motion directed at right angles to the surface (radially) is then transformed into a wave of decompression, and the surface layer's velocity in this direction is doubled. The resultant of this velocity and the tangential component gives the velocity of the surface particle after this partial reflection. The successive waves of decompression meet along the axis, and set up extension waves, which produce an extension in the interior of the sphere, beginning at the impact pole and spreading forward and outward. Round the impact surface this extension soon reaches the free surface of the sphere, and is partially stopped. The negative pressure thus moves forwards and is successively neutralized, while its radial component pulls the surface particles in towards the centre. When the waves neutralizing the extension meet along the axis, new waves of compression are set up, and the sphere pulsates after the impact.

In a solid, elastic sphere, the process will naturally be noticeably changed by the shearing stresses arising simultaneously. This is of little interest here, however, as we are concerned with finding the process in a liquid mass (the brain). In a liquid mass it is not necessary to take shearing stresses into account. A free spherical liquid mass is only conceivable in the form of a drop, and it is in full accordance with theory that, when encountering

an impact, this mass is dispersed in all directions, mainly in a plane at right angles to the direction of the impact. An enclosed liquid mass should, however, also react according to the theory given above. The intensity with which the waves are reflected will be determined, not, as in the case of a solid body, by its own cohesion, but by the elastic properties of the enclosing shell.

As this problem lends itself only with great difficulty to a theoretical, mathematical solution, the author has taken it up for experimental investigation. This investigation has included both determination of the frequency (and period) of the oscillations of an empty or full shell, and the measurement of impact times attending different blows to this empty or full shell.

The shell consisted of a hollow sphere of 1 mm brass with a diameter of 21.5 cm (two pressed hemispheres soldered together). The solder line was taken as the equator, and at one pole a packing cylinder was inserted, intended for the tight introduction of a probe. This probe was provided with a piezo-electric microphone. The crystal in the latter was built in between two metal plates and hung so as to give deflections for variations of pressure in the surrounding medium. The tests proved, however, that it was also sensitive, and to a higher degree, to vibrations in the probe. The potentials in the crystal were led after amplification to a cathode-ray oscillograph.

The impacts were produced with falling hammers, made of iron rods 5 cm in diameter. Four hammers of different lengths (20, 40, 80, and 160 cm) were available. The anterior end of each was hollowed out to correspond to the curve of the shell, and covered with thin leather. The velocities of approach were calculated from the height of the fall.

The impact times were registered by placing a contact (of aluminium foil) on the leather surface and short-circuiting a weak direct current voltage, which imparted a constant deflection to the cathode ray, over the sphere and the hammer during the time of impact. Readings were made after previously adjusting the sweep velocity of the oscillograph so as just to correspond to the duration of the impact. It was then easy to observe the small dark gap in the deflection that the ray made in its non-deviated position. For each value a series of readings were made on either side of the exact value.

When testing the piezo-electric microphone in the hollow sphere sine-shaped, damped oscillations were obtained. These were found not to depend on which of the hammers was used, and in frequency were independent of the magnitude of the velocity of approach. Further, they appeared to be independent of whether the sphere was empty (or, more exactly, filled with air) or filled with water.

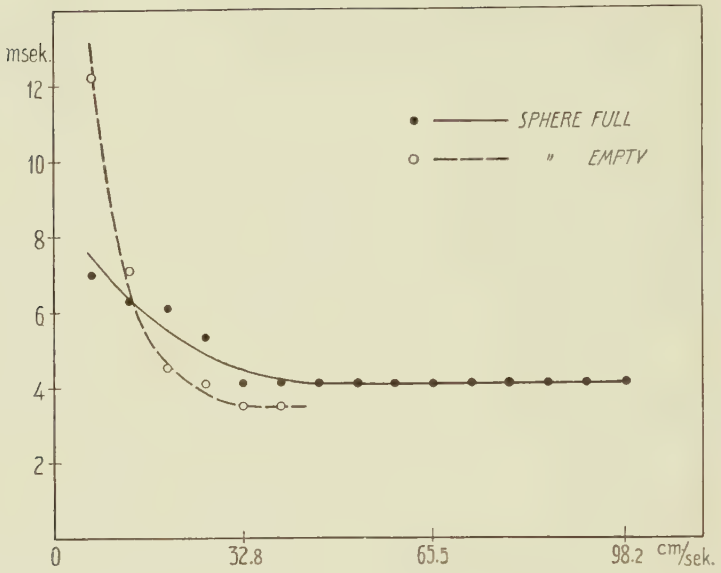
The probe was constructed for introduction at different depths along the axis of the sphere. When it was brought right in against the impact pole, a single frequency was obtained, which was regularly damped. When it was removed to its extreme position (against the opposite pole), a slower, similarly damped frequency was set up, on which the frequency observed at the impact pole was superimposed. Transitional forms were obtained in the intermediate positions. Synchronization with the sweep velocity of the oscillograph gave confirmation of the fact that the more rapid frequency was exactly the same at different points inside the sphere. As this frequency was also found in all variations of the impact, it can be deduced that it corresponds to the fundamental vibration of the shell as a totality. It is worthy of emphasis that this fundamental vibration is not perceptibly changed when the shell is filled with water.

This fundamental vibration is also detected as a short, rapidly diminishing tone during the tests. Other much higher frequencies can, however, also be induced in the complicated system: Blows on or near the packing cylinder or on the free end of the probe give an appreciably higher frequency, and by striking metal objects against the metal sphere we obtain the typical, very high-pitched ringing of metal. These types of oscillations are not set up by blows with the leather-covered hammers against the other pole which is intended for them.

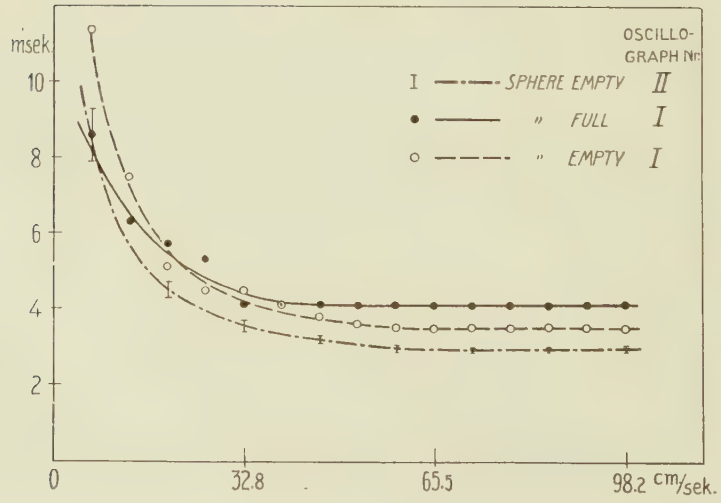
The determinations of the impact time are summarized in the accompanying figure 33 a—d. As is seen, they gave the same result in principle, regardless of which hammer was used. After the velocity of approach has reached a certain value (about 30 cm/sec.), the time of impact remains constant, independent of the velocity of approach. In all cases this constant time of impact is slightly shorter when the sphere is empty than when it is filled and when it is full of water 4—5 milliseconds. The times are of impact is prolonged, and this prolongation seems throughout to be more marked when the sphere is empty. When the sphere is empty the times of impact are between 3 and 4 milliseconds, and when it is full of water 4—5 milliseconds. The times are obtained by using two types of Philips' cathode-ray oscillographs. The values obtained agree well (see Fig. 33 b.).

The impact times thus obtained (the constant values at higher velocity of approach) correspond in magnitude to a complete

Fig. 33. *Times of impact in*

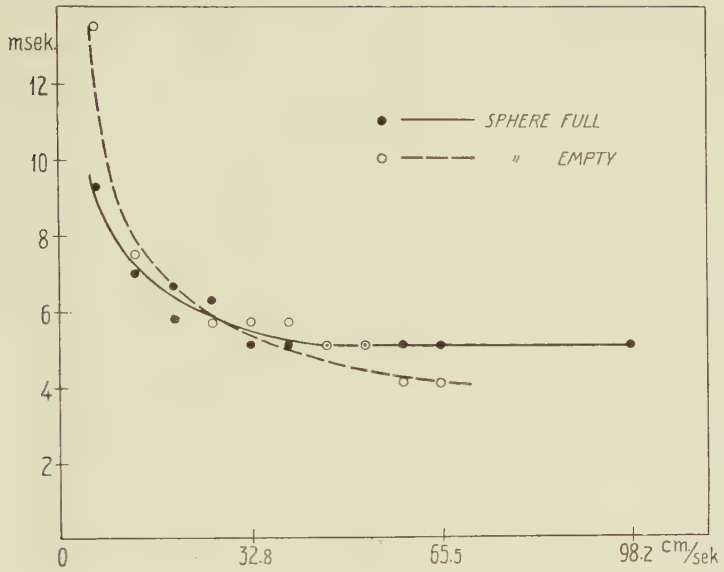


a. Length of hammer 20 cm.

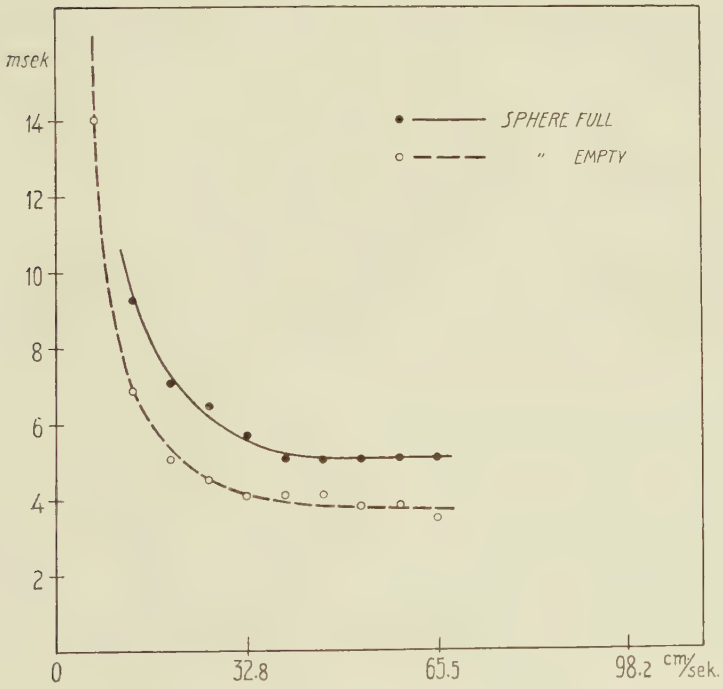


b. Length of hammer 40 cm.

*the author's experiments.**



c. Length of hammer 80 cm.



d. Length of hammer 160 cm.

* N. B Error in the figures: sek ought to be sec.
msek » » » msec (millisec).

oscillation of the always appearing oscillation, the fundamental vibration of the shell found in the frequency investigations.

This result seems to be in excellent accordance with the theory of elastic impact and the experimental results for axially colliding rods. According to the theory the time of impact is, as described above, equal to a complete oscillation in the rod with the smaller oscillating mass (or if these masses are equal, in the rod with the shorter oscillation period).

Of the objects used in the author's experiments, the hammers have the same oscillating mass (density $\times$ cross-sectional area $\times$ velocity of sound). The oscillating mass of the sphere cannot be calculated by the same simple rules as that of the rods. It can, however, be estimated to be less than that of the hammers, both empty and full. When the empty sphere is concerned, all three factors are less than the corresponding properties in the hammers: with the filled sphere, although the cross section is larger than that of the iron rod, the density — calculated as water — and the velocity of sound — calculated with knowledge of the sphere's fundamental vibration — are both so very much lower that the product must also be considerably lower than the value for the iron rods. It is therefore in accordance with the theory that the time of impact is determined by the elastic properties of the hollow sphere only.

The experiments thus show that the reaction of a hollow sphere to an impact is, in principle, the same as that of a rod struck axially: The energy transferred in the impact goes partly to accelerate the sphere and its contents, if any, partly to set the system in oscillation and thus to be stored as potential energy. At the beginning of the impact, the energy is divided equally between these two types. During the latter part of the impact, the potential energy reverts partly (or in special cases, wholly) to kinetic energy. What is left in the form of potential energy at the end of the impact remains as oscillations in the free object. The first wave (impact wave) is thus in a class by itself, in that it is always the strongest (in special cases, the only one). Regard will only be paid hereafter to the impact wave, not to the secondary waves, which are weaker and become damped after a longer or shorter interval. If the striking object has a greater oscillating mass and a longer oscillating period, the impact wave assumes

the form of a deformation successively spreading over the sphere from impact pole to opposite pole. This shortens the axis, while the equator is lengthened. When the wave front approaches the opposite pole, this latter begins to move forward in the direction of the impact, and the axis is lengthened while the equator is shortened. The impact ceases when this latter deformation has reached its maximum and the equator begins to lengthen again, simultaneously with the shortening of the axis.

The agreement between this phenomenon and that previously described when rods collide axially is so obvious that it is also justifiable to apply the equations found for the latter process to that in a hollow sphere, in any case for a schematic idea.

According to the main properties of colliding objects we get four different types of impact:

	Oscillating mass	Period of oscillation	Case
The striking object's	Greater	Greater	I
		Lesser	II
	Lesser	Lesser	III
		Greater	IV

As the hollow sphere has a very long period of oscillation, compared with that of a solid rod, there is very little probability of case IV developing in practice. This case will therefore not be discussed on the following pages.

The different types of impact thus established open new possibilities of explaining the different deformations of the skull with attendant different fracture forms in injuries from various objects. After all, a fracture is the result of a distortion exceeding breaking-point, and such a distortion requires a certain measure of work. The elastic strain-energy in the object struck is given by Equation 13 (p. 116),

$$A_\varepsilon = \frac{N_1^2 \cdot N_2}{(N_1 + N_2)^2} \cdot t \cdot \frac{v_0^2}{2}$$

where when N_1 = the oscillating mass of the instrument,
N_2 = the oscillating mass of the skull,
t = the time the impact force was active and
v_0 = the velocity of approach.

In Cases I and III the impact force is the same during the entire impact, and the time of impact equal to $2L_2$ and $2L_1$

respectively (L_1 = the half oscillation period of the instrument, L_2 = the half oscillation period of the skull). In Case II the impact force diminishes in the form of steps according to a geometrical series for each full period $= 2L_1$, and the impact ceases after the time $2L_2$.

While the acceleration proceeds during the whole of the impact (i. e. as long as the impact force is active and energy is transmitted), the deformation in a striking or struck body reaches its maximum after the body's half oscillation time, for after this it gets less again, and the potential energy is reconverted wholly or in part to kinetic energy. If the impact time is shorter than the body's half oscillation time, then the deformation naturally already reaches its maximum at the end of the impact time, as no further energy is added to augment it. Thus:
Maximum of potential energy (elastic strain-energy) in a struck hollow sphere (e. g. the skull).

Case No.	Striking object's oscillating mass	Striking object's oscillation period	Maximum reached after the time	Maximum of potential energy in the hollow sphere (skull)
I.	$>$ the skull's ($N_1 > N_2$)	$>$ the skull's ($L_1 > L_2$)	L_2	$\frac{N_1^2 \cdot N_2}{(N_1 + N_2)^2} \cdot L_2 \cdot \frac{v_0^2}{2}$
II.	$>$ the skull's ($N_1 > N_2$)	$<$ the skull's ($L_1 < L_2$)		
a.	$L_2 > L_1 > \frac{L_2}{2}$			= Case I
b.	$\frac{L_2}{2} > L_1 > 0$		L_2	$\frac{N_1 \cdot L_1}{4} \cdot \left[1 - \left(\frac{N_1 - N_2}{N_1 + N_2}\right)^{\frac{L_2}{L_1}}\right] \cdot v_0^2$
III.	$<$ the skull's ($N_1 < N_2$)	$<$ the skull's ($L_1 < L_2$)		
a.	$L_2 > L_1 > \frac{L_2}{2}$			= Case I
b.	$\frac{L_2}{2} > L_1 > 0$		$2L_1$	$\frac{N_1^2 \cdot N_2}{(N_1 + N_2)^2} \cdot L_1 \cdot v_0^2$

Now the minimum amount of work necessary to fracture the skull is assumed to be equally great whatsoever the form of the resulting fracture. It is therefore possible to calculate the kind of impacts giving fractures and developing in the case of different

types of instrument. As the skull, too, may have different elastic properties (due to changes from age and other individual differences), the skull's own properties are used as units in the calculations. Thus:

Skull's oscillating mass	N_2 g/sec
Skull's half oscillation period	L_2 sec
Skull's mass	$M_2 = N_2 \cdot L_2$ g
Instrument's oscillating mass	$N_1 = x \cdot N_2$ g/sec
Instrument's half oscillation period	$L_1 = y \cdot L_2$ sec
Instrument's mass	$M_1 = N_1 \cdot L_1 = xy \cdot M_2$ g
Energy required for fracture	A erg

The minimum velocity of approach required for a fracture can now be calculated as a function of x and y.

Case	Conditions	Minimum of velocity of approach
I, II a, and III a.	$\begin{cases} \infty > x \geqq 1 \\ \infty > y \geqq \frac{1}{2} \end{cases}$	$\frac{x+1}{x} \cdot \sqrt{2} \cdot \sqrt{\frac{A}{M_2}}$
II b.	$\begin{cases} \infty > x \geqq 1 \\ \frac{1}{2} \geqq y > 0 \end{cases}$	$\frac{2}{\sqrt{xy\left[1-\left(\frac{x-1}{x+1}\right)^{\frac{1}{y}}\right]}} \cdot \sqrt{\frac{A}{M_2}}$
III b.	$\begin{cases} 1 \geqq x > 0 \\ \frac{1}{2} \geqq y > 0 \end{cases}$	$\frac{x+1}{x\sqrt{y}} \cdot \sqrt{\frac{A}{M_2}}$

In practice, there is probably a correlation between oscillating mass and oscillation period in the instruments, as these usually increase in all dimensions when augmented in size. The oscillating mass then increases with the cross section, and the oscillation period with the length of the object. A number of more extreme possibilities are hereby ruled out. A quarter of the theoretically conceivable cases have also been ruled out *a priori*, namely, those cases where the striking object has less oscillating mass and longer oscillation period. It is, however, impossible to give in more detail the connexion, thus simplified, between the oscillating mass, oscillation period, and least possible velocity of approach for fractures. The fact nevertheless remains under all circumstances that objects with small oscillating mass and short oscillation period can only transmit an amount of energy necessary to fracture at

a very high velocity of approach (within the short time of impact). This amount of energy cannot spread during the time of impact over more than a limited area round the impact pole before the flow of energy ceases and the deformation again begins to be neutralized. Resulting fractures will therefore be restricted to the deformed region of the skull.

An elastic hollow sphere naturally communicates the effect of the impact on its fluid contents. When the impact begins and the impact pole is in the first place accelerated, this sets up a compression in the nearest fluid layer, which spreads out in the fluid with velocity of sound. When the deformation subsequently spreads over the shell, this in its turn will get further from or closer to the outer layer of fluid, setting up in it expansion and compression respectively, with attendant waves of negative or positive pressure in the fluid as a whole. The pressure in the fluid will be determined by the interference between all the waves proceeding from all points of the interior of the shell and spreading with velocity of sound in all directions. When the waves encounter afresh the inner side of the shell, they are reflected against it in a fashion determined by the elastic properties of the fluid and the shell. Both parts of the system will thus affect one another mutually, and the system as a whole be involved in oscillations whose frequency will depend on the elastic properties. In the experiments with the hollow sphere the fundamental vibration proved to be mainly dictated by the properties of the shell, and was affected only slightly by the water inside.

The impact wave is peculiar, however, since the system is then still partially quiescent, and layer after layer is set in motion progressively. During this time either the shell or the fluid will be 'leading', depending on the relation between the velocities of sound in each. If the fluid has a greater velocity of sound than the shell, the front of the first compression wave in the fluid will continually reach still quiescent parts of the shell and set them in motion. If the shell has the higher velocity of sound, the converse will be the case. In the former case, then, the initial change in the state nearest the inner side of the shell will be an increase in pressure; in the latter case, there will be either an increase or a decrease in pressure, depending on whether the shell's initial direction of motion in the point concerned has a centripetal or a

centrifugal component. The latter will assert itself particularly at the opposite pole, where (on account of symmetry) the direction of motion will be purely centrifugal. At this pole, then, a negative pressure will under these conditions develop. It begins to develop after exactly half the oscillating period (cf. Braquehaye, 1895). It must extend symmetrically round the axis (from impact pole to opposite pole), and it moves with velocity of sound into the fluid, where it encounters the positive pressure from the impact pole.

A theoretico-physical analysis of the process of the pressure wave calls for a further simplifying assumption, namely that the shell is completely rigid (the elasticity modulus infinitely great). Calculations of this kind have not been made previously. Docent Adolf Anzelius has now carried out such (see supplement) on the author's account: At the beginning of the impact, there must arise in the model changes of pressure in the fluid immediately under the shell in the form of positive pressure on the impact side and negative pressure on the opposite side. These changes spread with velocity of sound and interfere in the fluid mass. The positive and negative pressures hereby developed can, according to Anzelius, be calculated as functions of time and space. The result will be »that a marked pressure maximum (and minimum respectively) is in a short time set up near the central point of the sphere». Fig. 5 (on the last page of the plate sheet) shows on a meridian plane the highest values (on the impact side) and the lowest values (on the opposite side) in the different points during the first quarter of a whole oscillation period, given by 'isolines', connecting points with the same maximal or minimal pressure respectively during the time in question. During the second quarter the state on the two sides is reversed, and during the third and fourth they return by the same way to the initial situation.

3. Application to the skull and brain injuries.

a. The skull injuries.

In section 2 of this chapter the lower limit values for the velocity of approach required for fracture were calculated for different instruments on certain simplified assumptions. These

calculations showed: 1) This minimum velocity depends on the instrument's size according to certain functions (p. 129). 2) Small instruments can only cause fractures at a very high velocity. 3) When the instrument increases in size, this minimum velocity approaches asymtotically a value dependent on the properties of the skull only. If violence to the head is assumed to be asymmetrically distributed, the frequency diminishing when the velocity increases, which last seems a reasonable assumption, there will be in this latter group only a relatively small number of cases with very high velocity of approach. A clear difference is thereby set up between the two types (violence by means of large and small instruments respectively).

Quite different strain is set up in different velocities of approach (and thereby also, on an average, in different instruments). As has already been mentioned, large instruments (and moderate velocity) give a deformation of the skull as a whole, small instruments only a local deformation (granted that the impact wave can after the impact continue out over the whole skull.) In the former case, the strain approaches the state in bilateral pressing and involves the property in the material for which Mimey (1911) created the term 'fragilité de masse'. In the latter case at sufficient velocity a phenomenon appears which is specific for impact, and in which that property is seen which Mimey called 'fragilité structurale', according to the following schematic survey (see fig. 34.): When two rods impinge axially, the fractional extension $\left(\frac{x}{l} = \varepsilon\right)$ can, as has been shown already, also be expressed as the ratio between the change of velocity (v_s or $v_0 - v_s$) of the compressed part and the sound velocity (c) (p. 114). The breaking-point of a material is given, as we know, by the strain expressed by a certain value for ε (ε_{max}) or by the corresponding value for the stress. When the velocity of approach is so high that the calculated v_s (or $v_0 - v_s$) is greater than $\varepsilon_{max} \cdot c$, there is set up from the inner end a permanent distortion or a break which continues forwards in the rod as long as the impact proceeds (in fig. 34 only in the one rod). Between the boundary for this distortion and the wave front the rod is compressed to the elastic limit and assumes the velocity $v_{s\,max} = \varepsilon_{max} \cdot c$. The permanent distortion shortens the rod by the length $(v_s - v_{s\,max}) \cdot t$.

Mimey has checked this with experiments of shooting cylindrical bullets with different velocity at a block of a harder metal.

Among different fracture forms, the hole fracture in gunshot injuries is the most marked example of breaking by a small instrument at a high velocity of approach. The bone of the skull is here exposed momentarily to a strain exceeding breaking-point.

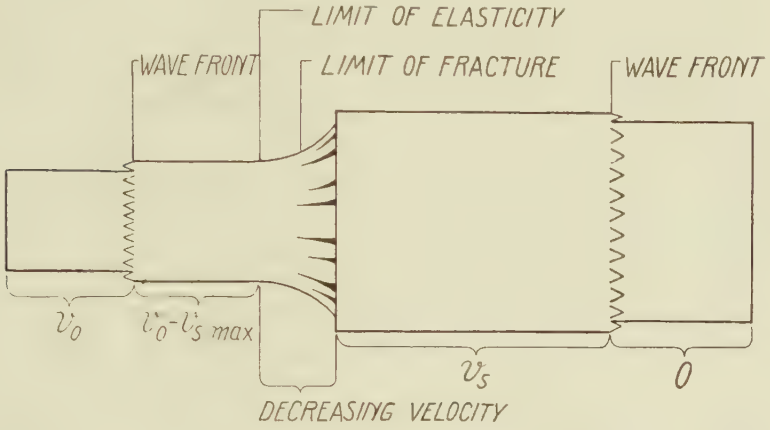


Fig. 34. *Axial impact of rods. Velocity of approach above* $v_{s\,max}$ $(= c \cdot \varepsilon_{max}$; for explanation see text).

The compression wave spreads forwards and outwards and the fracture follows at a proportionate distance. The way in which the consequently conical defect is set up has been discussed fully in Chapter II. (For the explanation of the explosive effect on the skull in gunshot injuries the author subscribes entirely to the hydrodynamic theory, as is also apparent from the discussion in Chapter II).

Violence of another kind with sufficiently high velocity (in practice lower than that of the projectile) gives fractures similar to hole fractures in gunshot injuries: There is a definitely shaped hole punched out in the lamina externa and a fracture surface widening inwards and ending with a large, generally rounded fragment of the lamina interna. It is worth mentioning again that Schumacher (1909) found a connexion between the velocity of approach and the extent of the fracture surface: The greater the velocity, the less the conical fracture surface diverges to the sides.

In these fracture forms the continuity between the site of violence and the skull as a whole is immediately broken, so there will be no acceleration of the latter.

A velocity of approach somewhat further diminished (and a sufficiently large instrument) gives, it is true, shaped fractures at the site of violence, but enough energy can nevertheless be transmitted to the skull outside the shaped fracture to set up acceleration and distortion outside it, also, albeit to a lesser degree than in the following case.

When the skull is pressed between two poles of pressure, a meridional fracture line from pole to pole is obtained. It is characteristic of the slow-acting, bilateral violence that the stress has time to spread evenly over the whole of the circumference and set up a fracture at the weakest place. After this first break the stress diminishes, and further pressure is needed for any new fracture, whose course will depend on the first one.

The fracture type resulting from an impact which is most similar to the fractures produced by bilateral pressing is the single meridional fissure. This is also characteristic of blows against large instruments (e. g. falls to the ground). In impacts it is on the other hand typical that there is no time for the stresses to level out. It is therefore possible that the same act of violence may occasion two or more simultaneous meridional fissures. These then radiate in all directions from the impact pole, and all as a rule get the same length towards the opposite pole. In these cases the acceleration and deformation of the skull as a whole are the greatest possible.

Cross fractures, arising secondarily, are sometimes observed between two or more such meridional fissures (see fig. 10 b.). The system of meridional fissures and parallel fissures is not fully developed until in the globus fracture. The author's limited material does not allow of any conclusions as to the particular type of violence which might be thought to produce such fractures. From the fracture type itself, however, it can be assessed that the effect of the violence was strongest in the vicinity of the impact pole, and that its effect on the skull as a whole was mitigated by the depression made possible by the complete fracture rings round the impact pole. If we analyse the fracture lines in such a system in detail, we can draw conclusions as to the time sequence in

which the different ones came into being. Thus, Specimen 48 (Fig. 17.), for example, shows from the type of ramification points that the fracturing must have begun immediately under the impact pole and then proceeded outwards in all directions with alternately longitudinal and latitudinal fractures.

b. The brain injuries.

The brain injuries are explained by one of the two following mechanisms: A. They may be determined by penetrating solid objects (the instrument itself or fragments of bone loosened by the violence) — direct brain injuries. B. In other cases they are determined by pressure below atmospheric in the brain substance — indirect brain injuries. The different types of injury fall into these two groups according to the following scheme:

A. Direct injuries, set up by penetrating solid object:

1. Blunt violence to the free head	Impact pole injuries
	Meridional injuries (cases with direct crushing)
2. Blunt violence to the supported head	All injuries
3. Gunshot	The smooth shot canal in cases without explosive effect on the skull
4. Edged violence	All injuries

B. Indirect injuries, set up by pressure below atmospheric:

1. Blunt violence to the free head	Meridional injuries (cases without direct crushing)
	Opposite pole injuries
	Injuries in the interior
2. Blunt violence to the supported head	———
3. Gunshot	The large injury in cases with explosive effect on the skull
4. Edged violence	———

Explanations of the scheme:

Group A requires no further explanation.

Group B.

1. Many earlier authors have given it as their opinion that the injuries at the opposite pole are set up by pressure below atmospheric (see Chapter II). This view has been fully developed by Goggio (1941, the pressure gradient theory). As has been described earlier on, all these authors assume different motions between different parts of the skull's contents, e. g. currents in the cerebrospinal fluid, in the blood vessels or through the different foramina in the skull. Such movements are, however, inconceivable during the short time the impact lasts. Nor are they necessary to explain the occurrence of pressure below atmospheric, for as shown above, such pressure below atmospheric sets in under the inner side of a shell filled with fluid when the velocity of sound in the shell is greater than in the fluid. This has been demonstrated experimentally in the investigations, mentioned several times, of Chipault and Braquehaye. This explains the opposite-pole injuries.

The calculations made by Anzelius and appended here can now also explain the haemorrhage patches in the interior of the brain by pressure below atmospheric. Earlier authors have pointed out that these patches are localized 'in the direction of the impact'. The regions with pressure maxima and minima, calculated by Anzelius, also lie along the axis and near the central point. Now, as the skull is not spherical but rather ellipsoid, and not rigid but elastic, we must of course imagine the waves of pressure in its contents to vary according to circumstances, but inner foci of negative pressure set up will probably in all circumstances be localized along the axis (from impact pole to opposite pole).

Similarly, the meridional brain injuries can (wholy or partially) be explained by the pressure below atmospheric that must arise between the edges of a fracture fissure. The more the strain of the skull forces the fissure to gape, the more pronounced must the pressure below atmospheric be. Whether or no the dura ruptures along the fracture, the brain substance will be sucked into or out towards the empty space between the edges of the fracture. As these close up again after the strain has ceased, any part of the brain surface left between them will be crushed.

2. Violence to the supported head gives no changes in the

head's state of motion, so that there is no physical background for pressure oscillations in the brain.

3. Only in the cases where the skull (wholly or in part) is exploded does the brain substance have a chance to expand. (As has already been shown, the projectile, which passes through the soft cerebral mass, seeks to throw surrounding particles outwards in all directions). This expansion widens the shot track, so that a large vacuum is set up round it, and outside this a pressure below atmospheric in the brain substance, diminishing peripherally. As early an author as Tilmann explained the gunshot injury to the brain in this way by 'Zerrung').

4. The injuries from edged violence will be dealt with together with the depression fractures (see below).

Anzelius' calculations cannot by themselves prove that the brain injuries are caused by pressure below atmospheric, for in the model he used all states are repeated rhythmically, so that each point with a pronounced pressure below atmospheric at one certain phase will have an equally pronounced pressure above atmospheric at another. (Cf. Braquehaye, who found both pressure above and below atmospheric, and who considered the injuries to be due to the former). Anzelius, that is to say, reckons with non-damped waves in a spherical fluid mass. In reality all wave motions are damped by the inner friction, and in so irregular a space as the cranial cavity the wave motions cannot repeat themselves; they interfere in an irregular way, which has a further damping effect. We can therefore take it that the pressures below atmospheric first set up are the strongest (i. e. the pressure below atmospheric at the opposite pole and the first focus in the interior of the brain, on the opposite-pole side). And it is at these points that we find visible brain injuries, not at the impact pole, where the pressure above atmospheric is greatest. The same rule holds for the gunshot injuries: Pressure above atmospheric is set up in all cases, but only when the skull is exploded does pressure below atmospheric set in, in which case it is primarily central (round the actual track of the projectile).

It is also *a priori* most probable that it is the pressures below atmospheric that do the damage, not the pressures above atmospheric. The latter cannot, after all, alter the structure of the practically speaking fluid tissue, while the former can lacerate it

or make it 'explode' by the liberation of dissolved gases or by cavitation.

c. The details in the picture in blunt violence to the free head.

The results obtained in the calculations on the different models are in the first place applicable to the cases without fracture. The cases with only short fissures could also be added to these, as they show completely similar cerebral injuries. In both these groups we see injuries never at the impact pole or along the possible short fissures, relatively seldom at the opposite pole, and relatively often in the interior of the brain. These latter are then placed as Anzelius's calculations would lead one to expect, as foci to the curved surfaces of the inner side of the skull. Of particular interest are those cases where there is a stronger and more concentrated haemorrhage patch in the interior on the opposite-pole side, and a more diffuse and milder one in the interior on the impact-pole side (Fig. 4.). The same mechanism seems to have been developed in Specimen 38 (Fig. 27.), although we have here a meridional fissure in the posterior fossa.

The cases with meridional fissure (or fissures) show injury never at the impact pole, often along one or more meridional fissures, practically always at the opposite pole; sometimes there are haemorrhages in the interior of the brain. These latter are then usually localized under the tentorium cerebelli (in the pons). The occurrence of the long, possibly gaping fissures naturally makes for an alteration in the course of the waves of pressure in the skull's practically speaking fluid contents. It has already been mentioned above how the pressures below atmospheric along the gaping fractures give meridional brain injuries. It is very likely that precisely these extra waves of pressure so derange the process in the interior that the 'foci' cannot be set up.

All the more usual are, instead, the injuries at the opposite pole. The cases lacking such injury can be referred to two quite different groups, one consisting of cases with violence to the sinciput, the other of cases in childhood.

Two important points of view have been advanced in the earlier discussion to explain the former group: 1) Duret (1878) considered the cervical vertebrae to avert a 'cone de soulèvement' in the

base of the skull. 2) Thoma (1909) maintained that the skull is elliptical and that its volume is therefore lessened when exposed to violence along the short axis. Both these points of view are undoubtedly correct, and the author does not wish to give the casting vote to either.

The systematic absence of opposite-pole injuries in young children is explained by their soft skulls. It has been shown above (p. 130) that when the shell has a lower velocity of sound than the fluid it encloses, this latter will 'lead' in impacts, and that pressure above atmospheric is then set up over the whole of the inner side of the shell. This, then, would apply to children.

Needless to say, the different types of opposite-pole injuries correspond to a different extent and depth of the pressures below atmospheric set up. The author's material is too small to be able to clarify the causes of these different types of brain injuries. It is, however, striking how well their general extent corresponds to Anzelius's calculations. Thus, the extent of the cortex injuries is given in their general type by the line '75 %', and the extent of cortex and medulla injuries by the line '50 %' in Fig. 5 (last side of the plate sheet). The material presented here could not make significant the connexion which might be expected between the depth of these injuries and the age at death.

Cases with depression fractures show, practically speaking, injury always at the impact pole, seldom along possible meridional fractures and at the opposite pole, and practically never in the interior of the brain. This is explained by the already mentioned fact that the fracture robs the site of violence of its firm connexion with the rest of the skull. Only a slight (and perhaps no) part of the energy transferred flows over the skull as a whole. Bone fragments and possibly the instrument itself penetrate the brain at the impact pole. The skull and brain are therefore accelerated only slightly or not at all, and the waves of pressure in the contents of the skull consist mainly of waves of pressure above atmospheric, proceeding from the impact pole. The faster and the more limited the application of violence is, the less will be the effect on the skull as a whole and on the brain beyond the impact pole. This group naturally also includes the applications of edged violence, which as we know do not display anything other than direct injuries to skull and brain.

The brain injuries can, as has been said, be explained by two different mechanisms. In both cases regard must be paid to the actual consistency of the brain. The direct brain injuries naturally arise from a breaking of the cohesion found in the tissue (in its capacity of solid body). As appears from the previous pages, the indirect brain injuries can be explained by the theoretically predicted pressure below atmospheric that must be set up in an enclosed liquid mass. The agreement between theory and experience is in this respect striking.

Summary.

All usual injuries to skull and brain can be classified as follows according to their genesis:

1. Injuries from blunt violence to the free head.
2. Injuries from blunt violence to the supported head.
3. Gunshot injuries.
4. Injuries from edged violence.

Group 1 shows the following connexion between the different injuries:

Nature of violence	Fracture type	Brain injuries				Time till death
		at impact pole	along meridian	at opposite pole	in the interior	
Plane	None	Never	Never	Often	Often	Long
	Short fissures					
	Meridional fissures	Never	Often	Nearly always	Sometimes	
Plane or shaped	Globus fractures	Often	Often	Often	Not observed	Short
Shaped	Sector fractures	Nearly always	Not observed	Seldom	Seldom or never	
	Segment fractures	Nearly always	Never	Seldom		

Group 2 shows only direct brain injuries.

Group 3 can be divided up as follows:

Energy transferred from projectile	Skull injury	Brain injury
Little	No explosion	Smooth track with the calibre of the projectile. Little surrounding haemorrhage
Much	Explosion fracture	Ragged track, wider than the calibre of the projectile. Extensive surrounding haemorrhage

Group 4 shows only direct brain injuries.

In order to explain the different types of injury, the theory of elastic impact (first advanced by Saint-Venant, 1867) has been applied to this special problem. Experiments on a hollow sphere are made to justify this method. Theoretical calculations (by Docent A. Anzelius, see supplement) show the process of positive and negative pressure waves in the fluid contents of a hollow sphere.

The type of the skull fracture depends on the *velocity of approach* of the instrument and the *time* of impact. Both of these are determined by the elastic properties of the instrument and of the skull, schematically thus:

	Time of impact	Velocity required for fracture
Small instruments	Short (depending on the elastic properties of the instrument)	Very high
Large instruments	Long (depending on the elastic properties of the skull)	Not so high (the under limit determined by the elastic properties of the skull only)

and further:

Velocity of approach	Distortion of skull	Type of fracture *	
		Main type	Special type
Very high	Within a more or less limited area round the impact pole	Depression fractures	Hole fracture Edged » Segment » Sector » Globus »
Not so high Below limit	As a whole	No depression	Meridional fissure(s) Short fissure(s) No direct fracture

* For definitions see page 57.

The brain injuries can be classified as follows:

A. Direct injuries, set up by penetrating solid object.

1. Blunt violence to the free head	Impact pole injuries Meridional injuries (cases with direct crushing)
2. Blunt violence to the supported head	All injuries
3. Gunshot	The smooth shot canal in cases without explosive effect on the skull
4. Edged violence	All injuries

B. Indirect injuries, set up by pressure below atmospheric.

1. Blunt violence to the free head	Meridional injuries (cases without direct crushing) Opposite pole injuries Injuries in the interior
2. Blunt violence to the supported head	None
3. Gunshot	The large injury in cases with explosive effect on the skull
4. Edged violence	None

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The Effect of an Impact on a Spherical Liquid Mass.

By

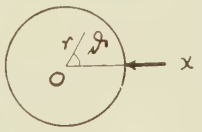
Adolf Anzelius.

Problem.

A liquid, enclosed in a rigid spherical vessel, is subjected to an impact at a point on its surface. It is desired to determine the pressure within the liquid as a function of the time.

Equations.

We assume for the sake of simplicity that the radius of the vessel = 1 and that the line of impact, which is chosen as the x-axis, passes through the centre of the sphere. The velocity and the pressure of the liquid are then rotationally symmetrical about this axis. The space coordinates are the radius vector $r = \sqrt{x^2 + y^2 + z^2}$ from the centre of the sphere O and the latitudinal angle ϑ measured from the axis of symmetry.



The general equation of oscillation is

$$\Delta^2\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = 0 \qquad (1)$$

where ψ is the velocity potential and c the propagation velocity.

If ψ be harmonic in time with the factor e^{ipt}, the wave equation becomes

$$(\Delta^2 + h^2)\,\psi = 0 \qquad (2)$$

where the wave-length is $\lambda = \frac{2\pi}{h} = 2\pi\frac{c}{p}$

The solution of equation (2) with spherical limitation has been previously treated.[1] The function ψ has the form

$$\psi = \sum R_n \psi_n$$

where R_n is merely a function of the radius vector r which satisfies the equation

$$\frac{d^2 R_n}{dr^2} + \frac{2(n+1)}{r}\frac{dR_n}{dr} + h^2 R_n = 0$$

The solution of this equation for the case when the motion terminates at the central point $r = 0$ is a Bessel function whose order is half of an odd integer

$$R_n(x) = (\quad)^n \sqrt{\frac{\pi}{2}}\, x^{-\left(n+\frac{1}{2}\right)} I_{n+\frac{1}{2}}(x) = \left(\frac{1}{x}\frac{d}{dx}\right)^{(n)}\left(\frac{\sin x}{x}\right) \qquad (x = hr)$$

In the case of rotational symmetry $\psi_n = r^n P_n$ where P_n is a spherical harmonics, i. e. a function of the latitudinal angle ϑ. We have, for example,

$$P_0 = 1$$
$$P_1 = \cos\vartheta$$
$$P_2 = \frac{1}{2}(3\cos^2\vartheta - 1)$$
$$P_3 = \frac{1}{2}(5\cos^3\vartheta - 3\cos\vartheta)$$

Disregarding the constants, the solution of equation (1) is therefore

$$\psi = \sum_n C_n r^{-\frac{1}{2}} I_{n+\frac{1}{2}}(hr) \cdot P_n(\vartheta)\, e^{ihct} \qquad (3)$$

This is the velocity potential. The pressure is then represented by the function $\frac{\partial \psi}{\partial t}$.

Boundary Conditions.

1. The radial component of the velocity must vanish at the surface of the sphere $r = 1$. The condition follows

[1] See e. g. A. E. H. Love, *Mathematical Theory of Elasticity*, Cambridge 1927, p. 278 ff.

$$2hI'_{n+\frac{1}{2}}(h) = I_{n+\frac{1}{2}}(h) \tag{4}$$

which equation determines the permissible values of h, i. e. the various wave-lengths of which the phenomenon is composed. The solution of equation (4) has been studied by Mc Mahon.[2] The first five roots are

$$h_1 = 2.082,\ h_2 = 5.940,\ h_3 = 9.206,\ h_4 = 12.404,\ h_5 = 15.579.$$

2. For the establishment of the correct boundary value of ψ or p for $t = 0$ exact knowledge of the impact is necessary, which is usually not available. If it be assumed, for example, that the impact is such that the liquid for $t < 0$ has a translational motion with constant velocity along the x-axis and is stopped at $t = 0$, the boundary value at $t = 0$ will be $\psi = v_0 x = v_0 r \cos\vartheta$. The corresponding solution (3) will contain only spherical harmonics of the first order P_1. The initial pressure will not be at a point, but spread over a hemisphere with its maximum at the axis of symmetry, with corresponding negative pressure on the opposite hemisphere. Within the sphere the pressure will vary linearly as r. The latter statement is certainly not true for a somewhat hard impact; the increase in pressure is here principally located at the surface and rapidly diminishes in the direction of the centre. On the other hand the assumption of a cosine distribution over the side on which the pressure is applied may be accepted as a first approximation.

From these considerations we write

$$p(r, \vartheta, t) = \sum_{\nu=1} C_\nu r^{-\frac{1}{2}} I_{3/2}(h_\nu r) \cos\vartheta \cos h_\nu c t \tag{5}$$

where, for $t = 0$ we shall have the internal pressure distribution $f(r)$ discussed above. Thus

$$\sqrt{r}\, f(r) = \sum_{\nu=1} C_\nu I_{3/2}(h_\nu r)$$

We are therefore led to the problem of expanding the function $\varphi(r) = \sqrt{r}\, f(r)$ into a Dini series of Bessel functions $I_{3/2}(h_\nu r)$ where h_ν are the roots of equation (4). The coefficients are [3]

[2] Annals of Math. *9*, 23 ff. (1894).

[3] See G. N. Watson, *Theory of Bessel Functions*, Cambridge 1922, p. 580.

$$C_\nu = \frac{2h_\nu^2}{(h_\nu^2 - 2)I^2_{3/2}(h_\nu)} \int_0^1 r\,\varphi(r)\,I_{3/2}(h_\nu r)\,dr \tag{6}$$

Beyond the above case $f(r) = r$ there are very few functions which give a simple form to the coefficients C_ν. In the case $\varphi(r) = r^{3/2}$ the integration may be performed exactly and we obtain

$$\int_0^1 r^{5/2} I_{3/2}(h_\nu r)\,dr = \frac{1}{h_\nu^2}\, I_{3/2}(h_\nu)$$

For an initial state which corresponds more to the true nature of the impact, we put $f(r) = r^n$ with increasing n. With the aid of Lommel's functions the resulting integrals may be determined by series. We have [4]

$$\frac{1}{\Gamma\left(\frac{\nu+\varrho}{2}\right)} \int \left(\frac{x}{2}\right)^{\varrho-1} I_\nu(x)\,dx = \sum_{s=0}^{\infty} \frac{\left(\frac{x}{2}\right)^{\varrho+s} I_{\nu+s}(x)}{\Gamma\left(\frac{\nu+\varrho}{2}+s+1\right)}$$

whence

$$\int_0^1 r^\varrho I_\nu(hr)\,dr = \frac{1}{2}\Gamma\left(\frac{\nu+\varrho+1}{2}\right) \sum_{s=0}^{\infty} \left(\frac{h}{2}\right)^s \frac{I_{\nu+s}(h)}{\Gamma\left(\frac{\nu+\varrho+1}{2}+s+1\right)} \tag{7}$$

Pressure Functions.

Through equations (6) and (7) the coefficients C_ν have been calculated for different values of n. As suitable tables are lacking, $I_{n+\frac{1}{2}}(x)$ has had to be calculated for different values of n and x, which was done with the aid of the formulae

$$I_{n+\frac{1}{2}}(x) = (-)^n \sqrt{\frac{2}{\pi}}\, x^{n+\frac{1}{2}} \left(\frac{1}{x}\frac{d}{dx}\right)^{(n)} \left(\frac{\sin x}{x}\right)$$

$$\frac{2p}{x} I_p(x) = I_{p+1}(x) + I_{p-1}(x)$$

The pressure distribution $p(r, \vartheta, t) = p(r, t) \cos \vartheta$ is thereby found. In the cases $n = 1$, 2 and 4 we obtain

[4] N. Nielsen, *Theorie d. Cylinderfunktionen*, Leipzig 1904, p. 97.

$$n=1:\ p(rt)=1{,}708\ \frac{1}{\sqrt{r}}I_{3/2}(h_1r)\cos h_1ct-0{,}184\ \frac{1}{\sqrt{r}}I_{3/2}(h_2r)\cos h_2ct+$$
$$+0{,}0919\frac{1}{\sqrt{r}}I_{3/2}(h_3r)\cos h_3ct-0{,}0571\frac{1}{\sqrt{r}}I_{3/2}(h_4r)\cos h_4ct+$$
$$+0{,}0411\frac{1}{\sqrt{r}}I_{3/2}(h_5r)\cos h_5ct$$

$$n=2:\ p(rt)=1{,}398\ \frac{1}{\sqrt{r}}I_{3/2}(h_1r)\cos h_1ct-0{,}412\ \frac{1}{\sqrt{r}}I_{3/2}(h_2r)\cos h_2ct+$$
$$+0{,}175\ \frac{1}{\sqrt{r}}I_{3/2}(h_3r)\cos h_3ct-0{,}0875\frac{1}{\sqrt{r}}I_{3/2}(h_4r)\cos h_4ct+$$
$$-0{,}0285\frac{1}{\sqrt{r}}I_{3/2}(h_5r)\cos h_5ct$$

$$n=4:\ p(rt)=1{,}023\ \frac{1}{\sqrt{r}}I_{3/2}(h_1r)\cos h_1ct-0{,}525\ \frac{1}{\sqrt{r}}I_{3/2}(h_2r)\cos h_2ct+$$
$$+0{,}330\ \frac{1}{\sqrt{r}}I_{3/2}(h_3r)\cos h_3ct-0{,}151\ \frac{1}{\sqrt{r}}I_{3/2}(h_4r)\cos h_4ct+$$
$$+0{,}0585\frac{1}{\sqrt{r}}I_{3/2}(h_5r)\cos h_5ct$$

In Figures 1, 2, 3 and 4 the pressure function p is shown graphically as a function of the time t and distance r from the centre of the sphere. Fig. 5 shows the highest positive pressure (and negative pressure) at each point of a diametral plane in the sphere for the case $f(r)=r^6$. It is found that a pressure increase occurs in the vicinity of the centre. This pressure in the case $n\geq 2$ is of the same order of magnitude as the initial pressure during the impact. — On the other side of the sphere $\frac{\pi}{2}<\vartheta<\frac{3\pi}{2}$ the pressure has the corresponding negative value.

Analogous treatment can be given to the case when the initial pressure has not a cosine distribution, but the impact is limited to a small area of the sphere's surface. One need then only express the initial pressure as a series of spherical harmonics on the surface $r=1$. This would, however, involve considerable work even if the distribution of the impact pressure were really known.

This preliminary treatment of the problem is sufficient to show that *a marked pressure maximum (with a corresponding minimum) appears after a short time in the vicinity of the centre of the sphere.*

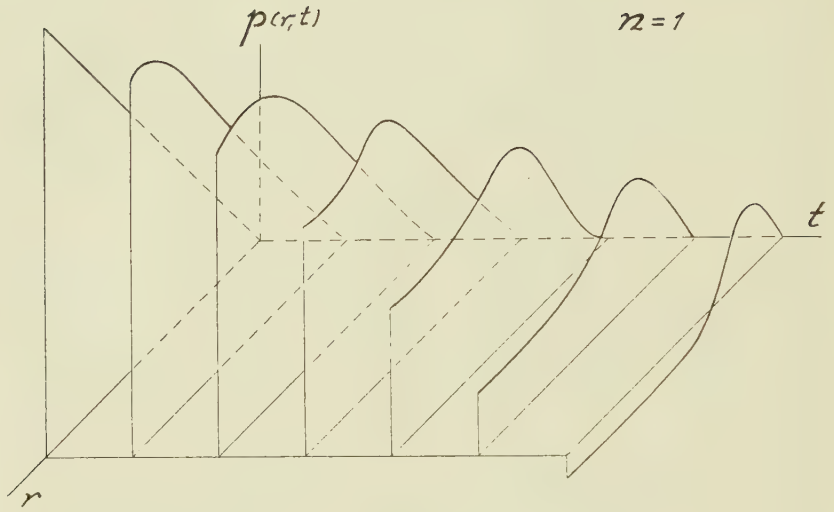


Fig. 1.

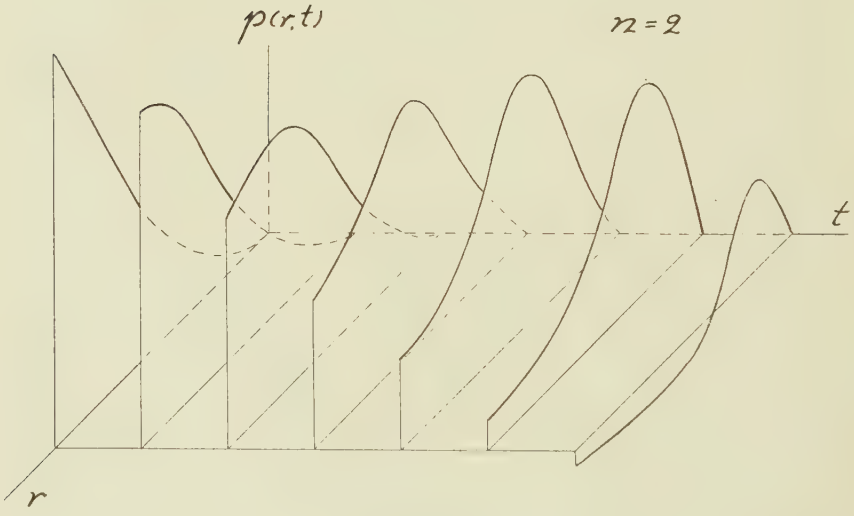


Fig. 2.

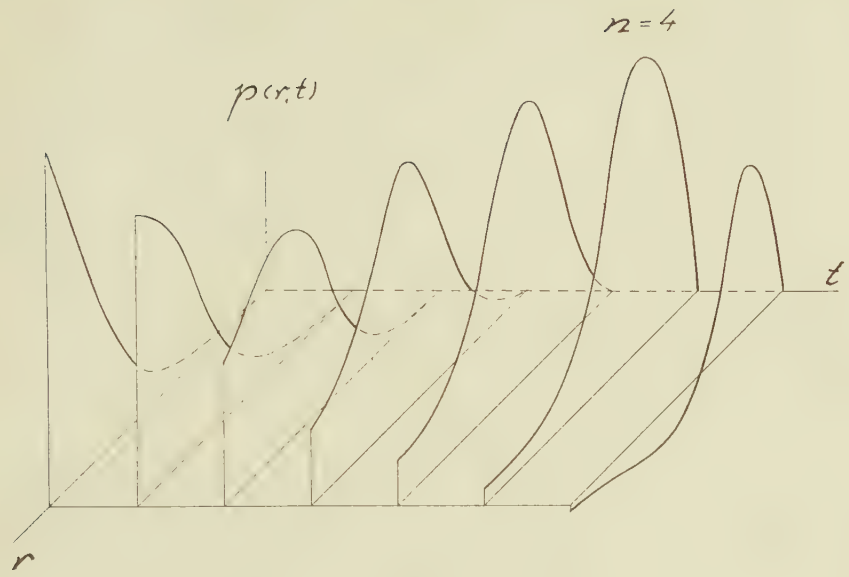


Fig. 3.

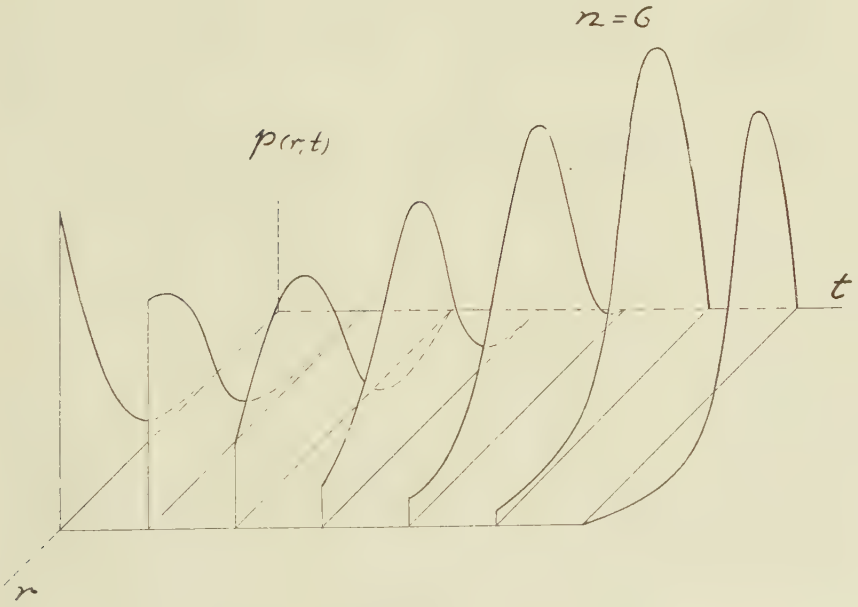


Fig. 4.

The Genesis of Skull and Brain Injuries

by

Hjalmar Sjövall

The Publication of this Thesis in English has been assisted by the British Council.

CORRECTIONS

p. 18 line 23:	*for* (1936)	*read* (1933 b)
p. 24 line 23:	*for* is two ways	*read* in two ways
p. 27 line 19:	*for* 0.003—0.004	*read* 0.004—0.005
p. 30 line 4:	*for* acceleration shock	*read* acceleration in impacts
p. 42 line 15:	*for* appearacne	*read* appearance
p. 63 line 25:	*for* orginate	*read* originate
p. 86 line 26:	*for* p. 00	*read* p. 45
p. 94 line 3:	*for* Plain	*read* Plane
p. 104 line 23:	*for* forehand	*read* forehead
p. 117 Fig. 32b:	Contact surface omitted in the fourth figure (between v_s—v_s)	
p. 123 line 31:	*for* and when ... are	*read* with water. When the velocities of approach are small, the time
p. 136 line 30:	*for* wholy	*read* wholly
p. 142 upper table:	*for* under limit	*read* lower limit

Tetrachoric correlation coefficients (tables 15, 16) are calculated according to Wahlund, S.: Lantbrukshögskolans Annaler, Vol. 2, Uppsala 1935, p. 181—244.

General explanations of the figures are to be found on the last page of the plate sheet (next to p. 65).